AGING AND SEMANTIC INTEGRATION IN SENTENCE PROCESSING: TESTING THE COGNITIVE WORKLOAD OF WRAP-UP

BY

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THESIS

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Abstract

The current study investigated the cognitive workload of sentence and clause wrap-up in younger and older readers. A large number of studies have demonstrated the presence of *wrap-up* effects, peaks in processing time at clause and sentence boundaries that some argue reflect attention to organizational and integrative semantic processes. However, the exact nature of these wrap-up effects is still not entirely clear, with some arguing that wrap-up is not related to processing difficulty, but rather is triggered by a low-level oculomotor response or the implicit monitoring of intonational contour. The notion that wrap-up effects are resource-demanding was directly tested by examining the degree to which sentence and clause wrap-up affects the parafoveal preview benefit. Older and younger adults read passages in which a target word N occurred in a sentence-internal, clause-final, or sentence-final position. A gaze-contingent boundary change paradigm was used in which, on some trials, a non-word preview of word N+1 was replaced by a target word once the eyes crossed an invisible boundary located between words N and N+1. All measures of reading time on word N were longer at clause and sentence boundaries than in the sentence-internal position. In the earliest measures of reading time, sentence and clause wrap-up showed evidence of reducing the magnitude of the preview benefit similarly for younger and older adults. However, this effect was moderated by age in gaze duration, such that older adults showed a complete reduction in the preview benefit in the sentence-final condition. Additionally, sentence and clause wrap-up were negatively associated with the preview benefit. Collectively, the findings from the current study suggest that wrap-up is cognitively demanding and may be less efficient with age, thus, resulting in a reduction of the parafoveal preview during normal reading.

To Kyle and Nathan

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Chapter I

Introduction and Literature Review

Rationale

Much in the way that aging brings about multiple trajectories of change in cognition, aging also impacts language processing and comprehension in a multitude of ways (see Burke & Shafto, 2008; Thorton & Light, 2006; Wingfield & Stine-Morrow, 2000). Knowledge-based products of cognition, such as vocabulary (Verhaghen, 2003), world and cultural knowledge (Ackerman, 2008), and domain-related expertise (Charness, 2009) remain stable throughout much of the adult lifespan; however, fluid cognitive processes that are responsible for the rapid encoding and transformation of information typically show declines with age (Park, Lautenschlager, Hedden, Davidson, Smith &, Smith, 2002; Salthouse, 1996; Salthouse, 2010). Consistent with the idea that aging has its largest negative impact on fluid abilities that place heavy demands on attentional processes (Stankov, 1988), age deficits are the most pronounced in aspects of language comprehension that are highly effortful. For example, online measures of processes that are automatic and obligatory are more often found to show age invariance (Federmeier, Van Petten, Schwartz & Kutas, 2003; Laver & Burke, 1993; Waters & Caplan, 2005). At the same time, memory for text shows relatively uniform declines with age (Johnson, 2003) and older adults tend to show reduced efficiency in the processing of propositional content during reading, which has subsequent effects on text recall (Hartley, Stojack, Mushaney, Annon, & Lee, 1994; Stine & Hindman, 1994).

However, several studies have shown that the recruitment of extra processing resources during reading may serve a compensatory function that underlies successful language comprehension and memory performance among older adults (for reviews, see Stine-Morrow, Miller & Hertzog, 2006; Stine-Morrow & Miller, 2009). One such potential compensatory function employed during reading is a phenomenon called *wrap-up,* which is thought to reflect attention to organizational and integrative semantic processes at the end of clause and sentence boundaries (Just & Carpenter, 1980; Rayner, Sereno, Morris, Schmauder, & Clifton, 1989; Rayner, Kambe, & Duffy, 2000). Wrap-up effects, which are measured as relative increases in reading time at clause and sentence boundaries, have been related to both subsequent memory performance (Stine, 1990; Stine, Cheung, & Henderson, 1995) and to facilitated downstream processing (Stine-Morrow, Shake, Miles, Lee, Gao, & McConkie, 2010) in both younger and older readers.

At the same time, there is some controversy about the nature of the wrap-up effect. The theory of wrap-up described above posits that it is a resource-demanding process (Just & Carpenter, 1980; Rayner et al., 2000). Results from studies finding age differences in wrap-up that predict subsequent memory suggest that the extra processing time at clause and sentence boundaries bears functional significance and may be an important aspect of language comprehension. On the other hand, others have argued that wrap-up is an early interpretive process that may be driven by low-level mechanisms such as a hesitation response to punctuation or a response to the implicit monitoring of intonational contour (Hill & Murray, 2000; Hirotani, Frazier, & Rayner, 2006). Under this view, wrap-up is obligatory, automatic and stimulus-driven, and thus, need not be related to processing difficulty. Although some (Warren, White, & Reichle, 2009) have argued that wrap-up may include both an early mechanism related to punctuation or intonation and a later mechanism related to semantic integration processes, the exact nature of these wrap-up effects is still not entirely clear.

While both an effortful processing theory and a low-level punctuation/intonation theory of wrap-up predict increases in reading time at clause and sentence boundaries, they do so for very different reasons. Thus, the current study was designed to elucidate the mechanisms driving wrap-up effects during sentence processing. Eye-tracking methodology was employed to examine how clause and sentence wrap-up affects the perceptual span, the field of useful information that can be processed during a given fixation (McConkie & Rayner, 1975), in younger and older readers. During normal reading, the word to the right of fixation is partially processed in parafoveal vision before the eye makes an overt saccade to that word. The evidence of a *parafoveal preview benefit* (Rayner, 1975; 1998), defined as the facilitation in fixation duration when a word is initially processed in parafoveal vision, suggests that covert attentional processing precedes an overt saccade to a word such that by the time it is first fixated, it has already received some early processing.

In the current study, a gaze-contingent boundary change paradigm was used to estimate this parafoveal preview benefit. On some trials, a non-word preview of N+1 was replaced by a target word once the eyes crossed an invisible boundary located between words N and N+1. Several studies have demonstrated that the parafoveal preview benefit varies as a function of both text difficulty (Henderson & Ferreria, 1990; Kennison & Clifton, 1995; White, Rayner, & Liversedge, 2005), and a reader's ability (Rayner, 1986; Chase, Rayner & Well, 2005). This suggests that the perceptual span is not biologically hardwired, but rather reflects attentional capacity needed to process a currently fixated word. Therefore, the notion that wrap-up increases cognitive workload (Just, Carpenter, & Miyake, 2003) was directly tested by examining the degree to which clause and sentence wrap-up affects the parafoveal processing of post-boundary words. If wrap-up is resource-consuming, then the preview benefit would be expected to be reduced across clause and sentence boundaries, especially for older adults.

The following background is presented in this chapter. First, I provide a broad introduction of research and theory in cognitive aging. Then, the following section covers the development of language comprehension through adulthood. I then review the nature of eye-movement control during reading, in order to provide background into the methodologies and common findings using various eye-tracking methods. Lastly, the literature on wrap-up effects is reviewed and I argue that the evidence supports the view of wrap-up as a resource-demanding process related to semantic integration during reading.

Cognition and Aging

Two divergent paths often characterize findings in cognitive aging research. In one route, aging is associated with monotonic declines in fluid cognitive abilities, which are based on the processing efficiency of the cognitive system. However, abilities based on the accumulation of knowledge and experience, so-called crystallized abilities, are often stable or show selective growth into adulthood (see Baltes, 1997; Schaie, 1994). Investigations into differential effects of age on cognitive ability have been studied since as early as the 1920's (Foster & Taylor, 1920). Cattell (1943) first introduced the terms of fluid and crystallized intelligence to differentiate between these two broad forms of cognition. The distinction between these trajectories still remains a robust finding in contemporary research. Tracking crystallized cognition across the lifespan illustrates that these abilities show relative age invariance, only declining in very late life. For example, older adults typically possess high levels of general world knowledge (Ackerman, 2008), and on average, also have a larger vocabulary from a lifetime of accumulated of verbal knowledge (Verhaeghen, 2003). On the other hand, aging brings reductions in working memory capacity (Bopp & Verhaeghen, 2005), speed of processing (Salthouse, 1996), and issues with inhibition (Hasher & Zacks, 1988) and executive and attentional control processes (Kramer & Madden, 2008).

While the terms fluid and crystallized ability are used here to describe these opposing age-related trajectories, there are a number of analogous conceptualizations worth noting. Some theorists and researchers refer to these divergent processes in terms of *cognitive mechanics*, to describe the processes that decline with age and *cognitive pragmatics,* to refer to the processes that are age invariant (Baltes, 1997). Likewise, Salthouse (1991, 2000, 2010) has referred to the abilities that decline with age as *process variables* and the abilities that are relatively age invariant as *product variables,* reflecting the finding that aspects of age resilient cognition are often the knowledge-based "products" of cognition. More recent research has found support for this dichotomy in the neural substrates that sub-serve these functions (see Raz & Rodrigue, 2006; Hedden & Garelli, 2004). For example, cognitive functions that tax speed of processing and executive function have been related to particular correlates of brain structure and function (e.g., declines in pre-frontal cortical volume; increases in white matter hyperintensities) that are highly vulnerable to biological aging (Gunning-Dixon & Raz, 2003). Thus, one useful rule of thumb is that the more resource-consuming cognitive processes will show larger age-related declines compared to those that are less demanding or those that rely on prior knowledge.

Mechanisms of cognitive aging. One major goal of cognitive aging research is to uncover the potential mechanism (or mechanisms) responsible for age-related changes in complex everyday tasks, such as language comprehension. Over the years, there have been several theories put forth to describe a common cause that accounts for age-related changes in cognition. The major assumption here is that there exists one (or a small number) of primitive mechanisms that decline with age and that these declines are the cause of changes in other cognitive abilities. As such, these theories may provide explanatory power towards understanding age effects on language comprehension.

For example, one pervasive theory in the literature is the processing speed or general slowing theory of cognitive aging (Salthouse, 1991; 1996). In brief, Salthouse argues that the major factor contributing to age-related differences in a wide range of cognitive abilities is a reduction in the speed with which cognitive operations can be executed. Evidence for this theory comes from a wide array of studies showing that performance on simple psychomotor speed tasks explain a large amount of the age-related variance in memory, reasoning, and other cognitive abilities, including reading comprehension (see Salthouse, 1996 for a review). However, a number of other hypotheses have been explored implicating executive control processes such as working memory (Craik, 1983, 1986; Light, 1991; Stine, 1995) or inhibitory control (Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999; Hasher, Lustig & Zacks, 2007) as the cause of age-related declines in performance in a broad range of tasks.

While the above examples are by no means an exhaustive list, most theories of cognitive aging share in common the assumption that the aging process results in some depletion of a limited pool of resources that are drawn upon during effortful tasks. What is less clear is what changes in this system (or systems) with age. That is, it is unclear whether aging results solely in a diminished capacity of the amount of information that can be held (Craik, 1983), a reduction in the processing efficiency or overall level of resources available to execute processes (Salthouse, 1996), or a reflection of declines in executive control abilities used to select and transform information (Engle, 1999; 2010; Hasher & Zacks, 1988; Kramer & Madden, 2008).

Compensatory mechanisms. Though there exists age-related declines in fluid cognitive abilities, evidence that these effects are reduced in more ecologically valid environments that more closely approximate everyday life (Anderson, Craik, & Benjamin-Naveh, 1998; Morrow & Rogers, 2008) and evidence that there is interindividual variability in these changes (Hertzog, Kramer, Wilson & Lindenberger, 2008) suggest a great deal of plasticity in cognitive function across the lifespan. One pervasive theme in the literature is the idea that older adults engage in compensatory strategies in many domains in order to combat age-related declines in cognition. At the neural level, the CRUNCH (Compensation Related Utilization of Neural Circuits Hypothesis; Reuter-Lorenz & Cappell, 2008) model has been formulated to explain the finding that older adults tend to show neural over-activation compared to younger adults when performing the same task. Older adults appear to recruit alternative pathways in homologous brain regions in order to maintain levels of performance in kind with their younger counterparts. These effects have been observed in a large variety of demanding cognitive tasks, including language processing (Grossman, et al., 2002; Persson, et al., 2006).

The possibility of age-related compensation has been considered in the cognitive aging literature for some time now, with a number of studies examining how older adults show compensatory gains in performance as a function of losses in ability (see Dixon & Backman, 1995). One area in cognitive aging where these effects are found is in studies revealing that those with higher levels of performance may reach these levels through differences in how they process information during the task. These adaptations, in part, include changes in processing strategies, changes in the allocation of time on task, and selection of appropriate tasks (Baltes, 1996; Riediger, Li, & Lindenberger, 2006). One interesting illustration of this comes from a study examining performance of older typists who maintain transcription speed at rates comparable to their younger counterparts, despite declines in processing speed (Salthouse, 1984). Expert typists use strategies such as increasing the "eye-hand span," whereby older (and slower) typists read further along in the to-be-transcribed passage than do their younger counterparts in order to maintain similar levels of performance. In a recent large-scale longitudinal study, Dixon and de Frias (2009) found evidence from the Victoria Longitudinal Study that older adults with mild deficits in memory function reported greater recent increases in the use of memory compensation strategies in everyday life when compared to older adults without memory impairments. This effect persisted over 12 years. Collectively then, these results suggest that, despite declines in processing abilities, older adults may employ compensatory strategies in order to maintain performance in everyday and complex cognitive tasks, including language comprehension.

The Nature of Language Comprehension through Adulthood

While a great deal of language comprehension appears to be spared with advancing age, it is now widely agreed that there are important changes in how we process text in older adulthood (Burke & Shafto, 2008; Thorton & Light, 2006; Wingfield & Stine-Morrow, 2000). The ability to comprehend written language is complex, involving the active processing and integration of information simultaneously, as the signal unfolds in real time, the qualitative nature of which is generally resilient with age. For example, at the word level, skilled readers encode and translate the orthographic signal along with phonological and morphological information and from this, access word-level lexical codes (Coltheart, Curtis, Atkins, & Haller, 1993; Seidenberg & McClelland, 1989). Readers parse sentences into syntactic constituents (Fodor, 1978) and take time to construct the propositional information (i.e., the idea units or the textbase*)* from the text online (Hartley et al., 1994; Stine & Hindman, 1994). From these processes, readers construct the larger discourse information from the text into a situation model (Kintsch, 1992; Zwaan, Langston, & Graesser, 1995). Given the complex and highly interactive nature of both interpretive processes and integrative post-interpretive processes in language comprehension, there is little surprise that aging impacts these systems in very different ways. Thus, in the following, I briefly review age effects on text processing at several levels, starting at a lower grain size and working up; I begin with a brief discussion of word-level processing in older adults and then discuss effects of age that operate at the sentence and discourse level.

Aging and word processing. Older adults appear to be relatively spared in the processes underlying orthographic processing and lexical access. A wide variety of studies have shown that visual word recognition does not show substantial age differences (Laver & Burke, 1993). For example, tasks that tap both offline (word association; Burke & Peters, 1986) and online (semantic priming; Burke & Harrold, 1988) measures show relative age invariance. In fact, similar effects of word frequency on reading time are found to be just about as large for older adults as they are for younger adults (Stine, 1990), and when there are quantitative differences, they sometimes appear to favor older adults, with older adults showing greater facilitation in lexical access (Laver & Burke, 1993; Lien, Allen, Ruthruff, Grabbe, McCann, & Remington, 2006; Speiler & Balota, 2000). One explanation for these effects is that older adults have accumulated a lifetime of verbal knowledge, and thus have a richer and more connected semantic network (Laver & Burke, 1993). In fact, a meta-analysis by Verhaghen (2003) showed a steady and reliable linear increase in vocabulary score with age, such that older adults scored on average .80 *SD* higher on standardized vocabulary tests than young adults (min = .63 *SD* [WAIS-R]; max = 1.62 *SD* [Nelson-Denny]).

Additionally, evidence for preserved lexical semantics among the old are found in event-related brain potentials (ERP). Because ERPs have excellent temporal resolution, they provide a window into determining the time course and particular cognitive processes underlying language comprehension (Garnsey, 1993). One component, the N400, is a negative going electrophysiological signal that peaks around 400 ms after the presentation of a stimulus. The N400 component is often linked to the processing of semantic information, with a large number of studies showing that the amplitude, scalp distribution, and in some cases, the latency of this response differs as a function of its predictability and semantic relatedness with prior information (see Kutas & Federmeier, 2011). When examining the processing of lexically similar and dissimilar word pairs in younger and older adults, Federmeier, Van Petten, Schwartz and Kutas (2003) found that both younger and older adults showed a similar reduction in the N400 to pairs of related words compared to unrelated word pairs, suggesting that aging does not diminish semantic retrieval at the lexical level. However, it is worth noting that these similar effects are not always found across methodologies. For example, Rayner and colleagues (2006), using an eye-tracking paradigm, found age differences in lexical access during normal reading such that older adults showed comparably longer fixation durations on lower frequency words than their younger counterparts.

Aging and sentence processing. As the grain size of analysis is increased and sentence-level factors are considered, the effects of age become more pronounced. Early studies examining age differences in the processing of syntax suggested that there exists an age-related deficit in memory for syntactically complex sentences (Kemper, 1987). Given that analysis of complex syntactic structures are believed to be dependent upon working memory capacity (Gordon, Hendrick & Levine, 2002; Fedorenko, Gibson, & Rohde, 2006), one explanation for these findings is that declines in working memory capacity may be the underlying mechanism of these changes (Just & Carpenter, 1992; Just, Carpenter, & Miyake, 2003; Daneman & Carpenter, 1980; Stine, 1995). A number of studies have found evidence for this from both offline measures of memory and comprehension and also from online measures of sentence processing (Carpenter, Miyake & Just, 1994; Stine-Morrow, Ryan, & Leonard, 2000).

However, Caplan and Waters (1999; Waters & Caplan, 1996, 2001) have argued that syntactic processing does not show age-related or working memory related declines. They argue that, whereas offline measures that assess comprehension of syntax may be sensitive to age and

WM, the process of syntactic parsing belongs to a different set of automatic and obligatory interpretive processes, which include lexical access, assignment of propositional values, and monitoring of intonational contour. Because these interpretive processes are automatic and obligatory and not dependent upon the same cognitive resources that are tapped by typical WM tests, they are not theorized to diminish with age. Evidence for this view comes from a lack of significant effects of age or WM on the online distribution of processing times when listening to complex syntactic structures in the auditory moving window paradigm (Waters & Caplan, 2001; DeDe, Caplan, Kemtes, & Waters, 2004). However, it is worth noting that some researchers, using other online measures of processing, such as eye tracking and self-paced reading, have found some evidence for age-related changes in online syntactic processing (Kemper, Crow, & Kemtes, 2004; Kemper & Liu, 2007; Stine-Morrow, Ryan, & Leonard, 2000).

Aging, text memory, and textbase construction. Age differences in sentence and text memory are pervasive in the literature (Johnson, 2003; Verhaeghen, Marcoen, & Goossens, 1993; Zelinski & Gilewski, 1988). A comprehensive meta-analysis by Johnson (2003), based on 194 studies, found large age deficits in text memory, with effect size estimates ranging from .66 to .78. On average, older adults perform at the 22nd percentile of the distribution of the younger adults in memory for text information. Thus, the quality of the representation that is kept in memory appears to change substantially with age. Models of discourse processing (Kintsch, 1998; Stine-Morrow et al., 2006; McNamara, 2009 for a review), assume that the array of information that is represented in memory operates at three levels: the surface level (i.e., the exact words and structure), the textbase (i.e., the propositional content, ideas given by the text) and the situation model (i.e., the representation of the situation inferred from the textbase).

Kintsch, Welsch, Schmaelhoefer, and Zimny (1990) found evidence for this distinction, demonstrating that the reader's ability to discriminate between recognition probes at these different levels showed differential rates of decay over time. They found that, while probe discriminability for surface information (i.e., the relative difference in discriminating between verbatim probes and paraphrase probes) declined over a short period of time, probe discriminability for textbase information (i.e., the relative difference in discriminating between paraphrase probes and inference probes) was more resilient and that probe discriminability for inferences (i.e., the relative difference in discriminating between valid inference probes and incorrect information), were resilient over the course of days. An important point is that it appears that the construction of textbase information is resource-consuming (Kintsch & Keenan, 1973; Hartley et al., 1994) and, as such, the textbase representation is often constructed with less than perfect fidelity.

Studies specifically examining age differences in the construction of text-based representations from sentences and discourse have found rather unequivocal evidence for age deficits in the processing efficiency of propositions (Hartley et al., 1994; Stine & Hindman, 1994; Stine-Morrow, Miller, Gagne, & Hertzog, 2008). For example, Hartley and colleagues (1994) used a staircase threshold method to estimate the relative processing time for older and younger adults to construct the propositional representation of sentences. They presented sentences of differing propositional density at varying time intervals to younger and older participants and found that the older adults needed more time per proposition for effective recall. Additionally, Stine and Hindman (1994) recorded reading times of older and younger adults reading sentences with varying levels of propositional density. Older adults took significantly longer to process the more propositionally dense sentences than their younger counterparts but still had overall worse recall. Importantly, examining effective reading time (reading time per proposition recalled) revealed that older adults took more time to encode the propositional content than younger adults. Not surprisingly then, there is research implicating the role of working memory in the relationship between age and textbase construction (Stine-Morrow et al., 2008; Smiler et al., 2003).

Eye Movements and Language Processing

Interest in the psychological processes underlying reading and written language comprehension can be dated back to some of the earliest work in experimental cognitive psychology (Huey, 1908). One major reason for this is that reading is a highly complex cognitive domain that draws interest from researchers not only interested in psycholinguistics, but also in topics as diverse as perception, attention, memory, and comprehension. Because early research in the psychology of reading was aimed at understanding the final representation of the text in memory (see Johnson-Laird, 1980) these studies often relied on offline measures of recall and comprehension.

Key to understanding language comprehension is not only the final representation, but also the moment-to-moment cognitive processes that occur during the construction of that representation. As such, a substantial literature in psycholinguistics has evolved to examine online measures of text processing and encoding. These methods include measuring word-by-word reading time (e.g., Aaronson & Ferres, 1984), lexical decision time (e.g., Meyer & Schvaneveldt, 1971), event-related brain potentials (e.g., Kutas & Hillyard, 1980), and eye-movements during natural reading (e.g., Just & Carpenter, 1980; Rayner, 1978; 1998), to name but a few. Each of these methodologies allows for a fine-grained measure of language processing that, importantly for inference about language processing, is highly temporally sensitive. While eye-tracking methods are used in many areas of cognitive psychology, such as scene perception and visual search (e.g., McCarley & Kramer, 2007), the use of eye tracking in reading research has surpassed its use in these other areas in terms of experimental utilization, the development of paradigms, and the development of well-specified theories and models (see Rayner, 2009 for a discussion). As such, an expansive literature exists examining eye-movement control during reading (Rayner, 1978; 1998; 2009; Rayner, Pollatsek, & Reichle, 2003; Staub & Rayner, 2007). The focus of this section of the thesis is on the use of eye-movement data to examine the time-course of language processes during reading.

Eye-movements during reading. During reading, the eyes alternate between brief pauses, called fixations, and short ballistic eye-movements, called saccades. The use of eye tracking allows the researcher to record the duration of these fixations and the latency and amplitude of these saccades, among other variables (e.g., pupil size, blinking). On average, eye fixations are between 225-250 ms during silent reading. Saccadic eye movements take approximately 30 ms and progress the eyes forward about 2 degrees, or about 7-9 letters forward in the text (Rayner, 1998; 2009).

The eyes make backward moving saccades, called regressions, about 15% of the time during normal reading. In some cases, these can be due to oculomotor factors such as when a saccade overshoots its intended target and a brief regression is made to correct for this. Importantly however, regressions can also be caused by processing difficulty during reading (Blanchard & Iran-Nejad, 1987; Frazier & Rayner, 1982) in which regressions are launched to areas of the text containing ambiguity or the source of the difficulty. In addition to early measures of reading time, such as first fixation duration (the duration of time spent during a first fixation on a target area), other measures that are gleaned from eye-tracking data are important in revealing underlying cognitive processes. For instance, longer words and infrequent words are often fixated more than once (McConkie, Kerr, Reddix, & Zola, 1989; Rayner, 1998). As such, other important variables include fixation measures that consist of various re-reading times and counts of the number of regressions in and out of target regions. Important variables for the current study will be discussed in more detail in a later chapter.

Cognitive components of eye-movements during reading. In line with the idea that cognitive factors drive the amount of time a word is fixated (Just & Carpenter, 1980; Rayner, 1998), there is now a large literature supporting the view that fixation duration is sensitive to processing demands of the text at the word, sentence, and discourse level. For instance, lexical factors largely determine fixation duration during normal reading, such that less frequent words tend to be fixated longer (Rayner & McConkie, 1976; Just & Carpenter, 1980). In addition, sub-lexical features affect fixation times. For example, Pollatsek, Hyönä, and Bertram (2000) showed that fixation times are affected by the frequency of the first morpheme in a bimorphemic compound (see also Pollatsek & Hyönä, 2005).

At the sentence level, sentential context affects fixation durations such that words that are more predictable from the context are processed faster than if they are embedded in sentences without context (Ashby, Rayner, & Clifton, 2005). A large number of studies examining eye movements during the reading of temporally ambiguous so-called “garden-path” sentences have revealed important effects on eye-movements (Altmann, Garnham, & Dennis, 1992; Ferreria & Clifton, 1986; Rayner & Frazier, 1987). For example, when readers experience syntactic ambiguity due to garden path sentences, they show inflated fixations and are more likely to regress back to the sentence to reprocess the ambiguity (Altmann et al., 1992). While the pattern of effects is somewhat similar for older and younger readers, older adults often make many more regressions and spend more time re-reading the garden path sentences in order to get the correct interpretation (Kemper et al., 2004). Importantly, a number of studies using eye tracking have revealed significant wrap-up effects (Just & Carpenter, 1980; Rayner, 1989, 2000; Kuperman, Dambacher, Nuthmann, & Kliegel, 2010; Stine-Morrow et al., 2010; but see Magliano, Graesser, Eymard, Haberlandt, & Ghoulson, 1993). These wrap-up effects are a major focus of this thesis and will be discussed in more detail in a following section.

The perceptual span and the parafoveal preview benefit. The eyes move forward during reading due to limitations of visual acuity. Within a given fixation, the visual field can be divided into three major sections: foveal vision, parafoveal vision, and peripheral vision. During reading, saccades are made to move the fovea, which only subsumes 2 degrees of visual angle, over the word to be processed. Although there is not a perfect link between what is being processed and what is being fixated (i.e., the *eye-mind assumption;* Just & Carpenter, 1980), these processes are tightly coupled such that covert attention precedes an overt saccade in systematic ways during reading (see Rayner, Pollatsek, & Reichle, 2003). Therefore, during a given fixation on a word, a large portion of that time will be due to processing on that given word, but in some cases, some will be due to processing from the preceding word (i.e., spill-over effects) and some will be due to parafoveal pre-processing of the following word. Early evidence for parafoveal processing came from the finding that a large number of words are skipped during normal reading, though they are certainly processed by the reader. Content words are skipped about 15% of the time while function words are skipped about 65% of the time (see Rayner, 1998). Therefore, while fixations are good measures of processing on a given word, there is a good deal of evidence that, in a given fixation, there is also some processing on the word to the right of fixation.

Moreover, a larger literature has shown that readers are only able to process visual information within a very small range in a single fixation. This field of useful information that can be processed during a given fixation is called the perceptual span (McConkie & Rayner, 1975). In skilled readers of English, the perceptual span is asymmetric, ranging from 3-4 characters to the left of fixation to about 14-15 characters to the right of fixation (McConkie & Rayner, 1975, 1976; Underwood & Zola, 1986; Miellet, O'Donnell, & Sereno, 2009). In addition to the perceptual span being skewed to the right, it is also vertically constrained, in that readers retain no information from lines of text both above and below the line currently being read (only in horizontal writing systems; when Japanese is printed vertically, reader's spans are vertically skewed in the direction of their eye-movements; Osaka & Oda, 1991). This specificity in the direction of the perceptual span appears to be a phenomenon that is largely specific to reading (see Rayner, 2009 for a discussion of the perceptual span in visual search and scene perception).

A number of clever paradigms have been developed in order to study the perceptual span during reading. Collectively, these are referred to as gaze-contingent display change paradigms. Because interest in the perceptual span has to do with how much information readers can take in during a given fixation, these paradigms all have in common the feature that they manipulate information outside of foveal vision during reading (with the exception of the moving mask paradigm, where an artificial foveal scotoma masks foveal vision during reading; Rayner & Bertera, 1979). One paradigm, the gaze-contingent moving window paradigm (McConkie & Rayner, 1975), was developed to determine the size of the perceptual span. In these experiments, a window directly in the participant's foveal field of vision is left uninterrupted while all of the text outside of this window is replaced with a mask of consonant strings or Xs. The researchers can vary the size of this window to determine what the minimum size of the window needs to be for participants to read normally. If readers have the fixated word and the word to the right available within this window, readers are unaware of the manipulation and reading goes along relatively normally. If the window is opened to have two words to the right of fixation available, then there is no significant slow down in reading rate. However, if only the currently fixated word is included in the window, with no information about the word to the right of fixation, reading is substantially interrupted (Rayner, Well, Pollatsek, & Bertera, 1982; see Rayner, 1998 for a review).

The findings from the moving window paradigm illustrate the importance of parafoveal word information in maintaining normal reading. Thus, not only do we process the word that is currently fixated but also we appear to begin processing the following word even before making a saccade to that word. In order to test this hypothesis explicitly, researchers developed another gaze-contingent paradigm, known as the boundary change paradigm (Rayner, 1975). In these experiments, an invisible boundary is placed between a pre-boundary target word (word N) and a post-boundary target word, just to the right of the pre-boundary target (word N+1). This boundary triggers a change in the display, which can be used to manipulate the presence of parafoveal word information during reading. Before the readers cross the boundary, N+1 is initially replaced by a non-word or mask. As the reader saccades from word N to word N+1, the mask is replaced with the target word N+1. This change occurs quickly, during the saccade, so that the participant is unaware that any such change occurred because visual processing is suppressed during saccades (Matin, 1974). The logic of this paradigm is that, if a reader obtains parafoveal information from the initially presented word N+1 while fixating word N, any inconsistency between what is available parafoveally (before the change) and what is available on the fixation (after the change) registers as an increase in processing time on word N+1. A number of studies using this paradigm have shown that, despite readers being unaware of the display change, when word N+1 is replaced with a mask, reading times on that word are larger than when the reader has a valid preview of the word. A meta-analysis of studies using this paradigm has shown that this *parafoveal preview benefit,* the relative benefit in processing time when one has a valid preview of the word, appears to be between 30 and 50 milliseconds (Hyönä, Bertram & Pollatsek, 2004).

The preview benefit as an index of cognitive effort. The size of the perceptual span appears to be variable, differing as a function of both text and reader characteristics. This suggests that the perceptual span is constrained by attentional and cognitive factors related to ease or difficulty of processing (Henderson & Ferreria, 1990). As such, examining differences in the preview benefit allow for a fine-grained online index of cognitive effort employed during reading. In this section, I review evidence suggesting that the size of the perceptual span, and thus, the preview benefit, differs as a function of cognitive factors in language processing.

In English, it is no coincidence that the perceptual span is asymmetric in the direction that the language is read. In fact, the size and direction of the perceptual span differs greatly depending on the language. In Japanese, a more densely packed orthography, the size of the perceptual span is only 6 character spaces to the right of fixation (Ikeda & Saida, 1978; Osaka, 1992). Additionally, in Chinese, a dense logographic writing system, the perceptual span ranges from 1 character to the left of fixation to 3 characters to the right (Inhoff & Liu, 1998). One of the more striking examples of this comes from a study by Pollatsek and colleagues (Pollatsek, Bolozky, Well, & Rayner, 1981), who found that Israeli bilingual readers of Hebrew and English had different perceptual spans depending on what language they were reading; when reading in Hebrew, participants showed an asymmetry to the left (consistent with the right to left direction of the Hebrew orthography), but had a typical right bounded asymmetry when reading in English.

Importantly, the size of the perceptual span appears to differ as a function of reader characteristics, such as reading skill. For instance, Rayner (1986) found that the perceptual span is smaller and less asymmetric in school age children who are still learning to read and in dyslexic readers, who have problems with decoding the orthographic signal (Rayner, Murphy, Henderson, & Pollatsek; 1989). More recently, Chase, Rayner, and Well (2005) examined individual differences in reading skill on the perceptual span among college-aged readers. They found that skilled readers showed a normal preview benefit but low-skill readers showed virtually no preview benefit.

The preceding examples suggest that characteristics of individual readers have effects on the size and symmetry of the perceptual span. More direct evidence for cognitive constraint of the perceptual span, however, would come from studies finding that difficulty of processing a currently fixated word produces reductions in the parafoveal preview benefit on the following word. There now exist a number of studies demonstrating this, suggesting that text difficulty (i.e., foveal load) constrains the perceptual span (Balota et al., 1985; Drieghe, Brysbaert, Desmet, & De Baecke, 2005; Henderson & Ferreria, 1990; Kennison & Clifton, 1995; White, Rayner, & Liversedge, 2005). For example, Henderson and Ferreria (1990), in two experiments, showed that text difficulty affects the preview benefit. In their first experiment, they manipulated the word frequency of the target word N and the availability of parafoveal preview of the post-target word N+1 (same word preview, non-word similar preview, and non-word dissimilar preview).

They demonstrated that, when the target word N was low in frequency, the parafoveal preview benefit on N+1 was greatly reduced compared to when the target word N was frequent (see also, White et al., 2005). In Experiment 2, they replicated this effect with syntactic complexity. Participants read garden path sentences in the boundary change paradigm, where the syntactically disambiguating word was the target word N (e.g., She warned {that} Harry *bought* small/tipoa gifts). They showed that the preview benefit on word N+1 was greatly reduced when the sentence was syntactically more difficult to process. Henderson and Ferreria (1990) argued that, when text difficulty was high on the fixated word, this foveal load decreased parafoveal processing on the post-target word.

Lastly, while a number of studies have examined individual differences in the size and symmetry of the perceptual span during reading, only until very recently have age differences in the perceptual span been examined. Rayner, Castelhano, and Yang (2009; 2010) have investigated the size and symmetry of the perceptual span in younger and older readers using both a moving window paradigm and a boundary change paradigm. Both studies have found that, while the perceptual span is somewhat reduced in older readers, they still obtain useful parafoveal word information from the word to the right of fixation. Interestingly, in the cases where older adults only fixated once on word N, they received a full preview benefit on the following word; it was only when older adults spent more time re-fixating word N, arguably due to processing difficulty, that the preview benefit was reduced (Rayner et al., 2010). However, it has yet to be explicitly examined if processing difficulty differentially impacts the perceptual span in older readers. Collectively then, these studies suggest that the parafoveal preview benefit provides a sensitive measure of cognitive effort during text processing. An important task is to understand what features of reader and text characteristics influence this preview benefit.

Wrap-up Effects During Reading

Experimental research in reading, and in language processing more wholly, has shown that many of the linguistic computations that underlie the interpretation and representation of language occur immediately and are incremental in nature (Clifton, Staub & Rayner, 2007; Just & Carpenter, 1980; Tanenhaus, Spivey- Knowlton, Eberhard, & Sedivy, 1995; Rayner, 1998; Van Petten, 1993). At the same time, evidence for wrap-up effects, increases in reading time at clause and sentence boundaries, suggests that extra processing is being allocated at the end of major syntactic units (Just & Carpenter, 1980; Rayner et al., 1989; Rayner, Kambe & Duffy, 2000). It has been suggested that these peaks in reading time reflect effort towards integrating the semantic information within a clause with prior discourse and in creating a representation of the information in memory (Just & Carpenter, 1980; Rayner, Kambe & Duffy, 2000).

Some of the earliest demonstrations of wrap-up effects date back to the 1970's, with findings from Doris Aaronson and colleagues (Aaronson & Scarborough, 1976; 1977), showing that reading times follow a scalloped pattern, with increases at clause and phrase boundaries. Just and Carpenter (1980) coined the term "sentence wrap-up" to describe their findings from a series of regression analyses on eye-movement data, demonstrating that readers showed increased fixation times at sentence boundaries. They argued that these points of increased reading times reflect places of integration of the information within that sentence as well as important places where infelicities in the text are resolved (i.e. referential cohesion and ambiguity resolution). Consistent with some models of discourse comprehension (Kintsch & van Dijk, 1978), readers may define clauses and sentences as processing units (i.e., input cycles), and as such, these peaks may reflect time to integrate the conceptual and semantic information from within that input cycle into a larger representation of the text.

Rayner and colleagues (1989, 2000) examined the existence of clause wrap-up effects on eye movements, using an experimental paradigm (see also Millis & Just, 1994, for similar findings using experimental methods in self-paced reading). In these studies, participants read sentences such as:

1. Since his friend owned the *instrument* already, he was able to find out where to get one.

2. Since his friend owned the *instrument*, already he was able to play simple melodies.

They found that the target word *instrument* was fixated longer in sentences like 2, when it marked a clause boundary, compared to in 1, where it appeared in a clause internal position, even though everything up to the point of the clause was identical across conditions. Additionally, they found that participants made larger saccades out of the target word at a clause boundary, compared to a clause internal position. More recently, Kuperman, Dambacher, Nutmann, and Kliegel (2010) found evidence for wrap-up effects from a large-scale corpus of eye movement data, based on sentence and paragraph reading in English, Dutch, and German. They found sentence wrap-up effects that emerged in all three of the corpus results, with a strong, non-linear, positive relationship between absolute word position and fixation duration such that words located at the end of the sentence were fixated between 30-50ms longer than sentence-internal words. This effect was still significant after controlling for a number of predictors of reading time that might covary with word position including word class, frequency, length, predictability and saccade amplitudes of word N, N+1, and N-1.

Though these studies collectively show that readers allocate more time at clause and sentence boundaries, it is not exactly clear why this is the case. The presence of these effects does not argue against an immediacy/incrementally view of language processing. Rather, while there exists ample evidence that many linguistic computations are initiated immediately, what is less clear is the specificity and depth with which these processes are computed. Recently, studies of underspecificity in language comprehension have argued that much of language processing can be effective without being fully represented (see Ferreira, Bailey & Ferraro, 2002; Sanford & Sturt, 2002). For example, the final syntactic (Christianson, Hollingsworth, Halliwell, & Ferreria, 2001; Swets, Desmet, Clifton, & Ferreira, 2008) and semantic representations (Daneman, Lennertz, & Hannon, 2007; Barton & Sanford, 1993) are often shallow or underspecified. Under this view, while linguistic processes may be initiated immediately, it is not necessarily the case that all processing is carried out in full depth at that word (and in some cases never fully carried out at all). The full scope of language comprehension may involve both incremental and immediate processing and integrative and connective processes (Green, Mitchell, & Hammond, 1981; Traxler, Bybee & Pickering, 1997). Thus, wrap-up effects may emerge because they serve as important points in which the semantic and conceptual information within a clause or sentence is connected with prior information in working memory in order to construct a more complete and specified representation of the meaning of the text.

Evidence for wrap-up as semantic integration. Under a resource view of wrap-up effects, such as the one described above, these clause and sentence-final peaks in reading time should differ as a function of the processing demands inherent during language comprehension. In the following section, I review the literature suggesting that wrap-up effects are determined, at least in part, by processing difficulty associated with conceptual integration. These include evidence from a number of studies showing that (a) text demands influence wrap-up in reading, (b) there are facilitative effects of knowledge on wrap-up, (c) unique wrap-up effects are revealed in event-related brain potentials, and (d) there exist age and individual differences in wrap-up that impact subsequent text memory.

Processing demands at wrap-up. Haberlandt and Graesser (1989a) examined the effects of informational complexity on reading time at clause and sentence boundaries. In a self-paced word-by-word reading time task, they had participants read expository and narrative passages that varied in the cumulative number of new arguments per sentence. While they found that the number of new arguments was a significant predictor of reading time, importantly, it significantly interacted with reading time at boundary sites, such that increasing the number of new arguments resulted in inflated reading times at clause and sentence boundaries more so than at non-boundary words.

Daneman and Carpenter (1983) had similar findings from a study presenting participants with passages with inconsistencies such that a particular word was locally ambiguous (i.e., …he went and looked among his baseball equipment. He found a *bat* that was very large and brown and was flying back and forth in the gloomy room). While they found evidence that readers immediately process the inconsistency on the ambiguous word, they also found significant effects of ambiguity at sentence boundary sites. Importantly, an offline probe task revealed that readers had difficulty resolving the inconsistency if a sentence boundary intervened, compared to a condition where there was no sentence boundary (He found a *bat*. It was… vs. He found a *bat* that was…). This effect differed as a function of working memory, such that small span individuals were most affected while high span individuals were not. Thus, processes that occur at the end of the sentence reduced the availability of verbatim surface information and the finding that this process taxed low-span readers more suggests that it is resource-consuming. Consistent with the idea that information within the last clause is reactivated at wrap-up sites, Balogh and colleagues (Balogh, Zurif, Prather, Swinney, & Finkel, 1998) used a cross-modal lexical priming task to examine the activation of an antecedent before a gap site, at a gap site and again at the end of the sentence. While the antecedent was not activated at the pre-gap site, they found significant priming at the gap site (i.e., gap-filling; Tanenhaus, Boland, Garnsey, & Carlson, 1989) but, they also found evidence for this reactivation at the sentence-final position, suggesting the referent was activated again at wrap-up.

More recently, Stine-Morrow and colleagues (Stine-Morrow, et al., 2010) examined the effects of clause wrap-up on downstream processing at the sentence-final position. In both a self-paced reading experiment and an eye-tracking experiment, they manipulated the salience of an early boundary, by either leaving the boundary unmarked (i.e., no comma/period), marking the boundary with a comma, or marking the boundary as sentence-final. They then examined reading times at this first boundary site and subsequent processing at the next boundary (always a sentence-final position). Though the syntactic boundary remained the same, manipulating boundary salience increased reading times at the first boundary site. Importantly, in both experiments they found a "pay-now-or-pay-later" effect. That is, when readers showed larger wrap-up effects at earlier clause boundaries (as a function of boundary saliency), they also showed reduced wrap-up at the final sentence boundary, suggesting that when readers increased their allocation of attentional resources to integrating the semantic representation at earlier and more minor boundaries, they yielded benefits in downstream processing, at the sentence-final word.

Effects of knowledge on wrap-up. Early studies have shown that manipulating pre-existing knowledge of target texts facilitates the processing of those texts and increases subsequent recall of that information, relative to a "no knowledge" control (Sanford & Garrod, 1981). Importantly, prior knowledge of text information has been shown to facilitate wrap-up effects during reading, suggesting that knowledge allows for easier integration of new information into an existing representation. In several experiments, Sharkey and Sharkey (1987) had participants read target sentences in a self-paced reading paradigm. They manipulated prior knowledge by having one group of participants read sentences with no context while the other group first read a story related to the content of the target sentences. They found significant increases in reading time at the sentence-final position and that knowledge had no facilitative effect on sentence-internal processing. However, at the sentence-final position, the group in the knowledge condition showed decreased reading times compared to the control group. Wiley and Rayner (2000) found similar results in an eye-tracking study in which they manipulated the presence of a disambiguating title before having participants read the same target passages. They found that the knowledge-title manipulation only decreased end of sentence reading times, indicating facilitated wrap-up. Using self-paced reading, Miller & Stine-Morrow (1998), examined effects of knowledge on both clause-final and sentence-final reading times and found that high knowledge readers were facilitated in processing at both clause and sentence boundary sites.

Wrap-up effects in event-related brain potentials. Evidence from ERP studies of language processing have also revealed unique sentence-final wrap-up effects (Ditman, Holdcomb, & Kuperberg, 2007; Hagoort, 2003; Hagoort, Brown & Groothusen, 1993; Osterhout, 1997; Osterhout & Nicol, 1999). Hagoort (2003) had participants read sentences with syntactic and semantic violations in both sentence-internal and sentence-final conditions, while an electroencephalogram (EEG) recorded brain activity across 13 electrode sites. He found that component brain responses to the violations differed significantly in the sentence-internal and sentence-final target words. Specifically, the syntactic violation in the sentence-internal position, unsuprisingly elicited a P600 effect, which is often found in response to violations of morphosyntax, phrase structure, number/case agreement, and other syntactic violations (e.g., Munte & Heinz, 1994; Hagoort, et al., 1993). However, in the sentence-final position, both a P600 and a concomitant N400 effect were found as a result of the syntactic violation. Importantly, all sentence-internal violations (syntactic, semantic, and syntactic + semantic) elicited a larger N400 effect in the sentence-final word. Thus, it appears that violations at the syntactic and semantic level resulted in downstream semantic processing difficulty at the sentence-final word, perhaps at the point where the overall sentential information is integrated into a larger representation of meaning.

Age differences in wrap-up and effects on recall. Evidence from several studies examining wrap-up in older adults suggests that there are age differences in wrap-up and that individual differences in these effects have an appreciable influence on subsequent memory performance. Some studies have found age differences in wrap-up at sentence boundaries, with younger adults showing larger effects. These studies suggest that older adults may not allocate extra processing resources at the ends of sentence boundaries and as a result, memory performance is poorer (Stine, 1990; Stine et al., 1995). However, when older adults show comparable sentence memory performance to younger adults, older adults often allocate extra processing time to sentence (Miller et al., 2004; Stine-Morrow et al., 2001; Smiler, Gagne, & Stine-Morrow, 2003) and clause (Miller & Stine-Morrow, 1998) boundaries. These studies suggest that one way in which older adults maintain comparable memory performance to their younger counterparts is to compensate by allocating extra processing resources to semantic and conceptual integration at minor and major syntactic constituents.

Other studies examining age differences in reader goals and the effects of task demands suggest that wrap-up reflects semantic integration. Some (Aaronson & Scarborough, 1977; Stine-Morrow, Milinder, et al., 2001; Stine-Morrow et al., 2008) have found that wrap-up is inflated when readers are asked to recall subsequent text as opposed to answering comprehension questions. Interestingly, this increase in wrap-up in the recall condition appears to be exaggerated in older adults. In order to maintain high levels of recall, older adults adapt their online processing, in part by showing more frequent and larger clause wrap-up (Stine-Morrow et al., 2001), perhaps in order to break up the text into smaller processing units. Age differences in wrap-up are not only demonstrated in reading, but also in self-paced listening (Fallon, Peelle & Wingfield, 2006; Waters & Caplan, 2001). Fallon and colleagues (2006) had older and younger participants listen to object relative, subject relative, and active conjoined sentences in an auditory moving window paradigm under goals of either comprehension or recall. They found that older and younger adults showed wrap-up effects at the ends of sentences, but that this effect was moderated by task demands and age. Importantly, and in line with prior reading research, older adults showed inflated sentence-final listening times in the recall condition, and when recall was presented first and followed by a comprehension goal, these inflated reading times from the recall condition persisted into the comprehension condition for the older readers.

Dwell time/oculomotor accounts of wrap-up. Another recent view of wrap-up effects is that they may reflect processes that are more automatic and obligatory, with some suggesting that wrap-up is a byproduct of a low-level process. Under this account, much of the increase in reading time at clause and sentence boundaries is due not to resource demanding cognitive processes that are related to the integration of semantic information. Hill and Murray (2000) argued that wrap-up effects manifest as an oculomotor hesitation response to punctuation during reading and are not caused by the need to integrate semantic information during reading. Hirotani, Frazier, and Rayner (2006) recently examined the effects of punctuation and intonation on wrap-up. Participants read a number of different clause constructions that are related to intonational phrase boundaries in speech. They argued that because semantic and syntactic analysis is incremental, it is not clear what incomplete work is left to be done at the end of clauses and sentences. They proposed a *dwell-time* account, in which wrap-up is related to punctuation or the monitoring of the intonational properties of the sentence and "need not be related to the amount of work to be done at the clause boundary" (p. 426). In fact, they find evidence for wrap-up at brief unambiguous clauses and at the end of phrase boundaries such as vocatives (i.e., *John*, go to the library for me). Additionally, they found that the magnitude of wrap-up effects did not differ as a function of sentence complexity (see also, Warren, White, & Reichle, 2009).

It is also important to note that several studies (Hirotani et al., 2006; Rayner, 2000) have found that readers make larger saccades out of clause and sentence boundaries. As pointed out by Hirotani and colleagues (2006), this seems to be problematic for a semantic integration view of wrap-up, as long fixations associated with processing difficulty are normally followed by short saccades. However, one argument that has been made (Staub & Rayner, 2007) is that, because wrap-up reflects points where the contents of working memory may be "cleared" online, that this may result in longer fixations and concomitant larger fixations out of the boundary area.

The Present Study

The exact nature and extent of the cognitive demand of sentence and clause wrap-up is not clear. Thus, the present study was designed to test several hypotheses about the cognitive workload involved in wrap-up. I adopted a gaze-contingent boundary change paradigm in order to examine the degree to which sentence and clause wrap-up has effects on the perceptual span during normal reading. Under a semantic integration viewpoint of wrap-up (Just & Carpenter, 1980; Stine-Morrow et al., 2010; Rayner, 2000), processing of sentence and clause-final words should produce a foveal processing load (Henderson & Ferreria, 1990) and thus, parafoveal preview on the following word should be reduced compared to conditions when the same words appear in a sentence-internal positions. However, if wrap-up is solely the result of a dwell/hesitation response to punctuation or prosodic phrase boundaries, then the presence of clause and sentence boundaries should not constrain the parafoveal preview of the following word.

Furthermore, these effects were examined in both younger and older readers in order to investigate how aging impacts both the perceptual span and wrap-up and importantly, how these jointly determine processing. Caplan and Waters (1999; Waters & Caplan, 1996, 1997, 2001; 2005) have argued that there exists a separate language interpretation resource used in language comprehension. They have found some support for the idea that there is an independent verbal working memory system dedicated to online sentence processing and that aging does not diminish the resources available to this system. However, a number of other researchers have found support for a capacity constrained comprehension model (Carpenter et al., 2003; Fedorenko et al., 2006; Gordon et al., 2002; Just & Carpenter, 1992; King & Just, 1991), in which early language processing draws on a similar pool of resources as conscious and controlled processing, that which is subject to depletion from a number of sources, including age.

Under a capacity-constrained comprehension model, in which age related declines in processing resources affects the processing efficiency of language comprehension, one would expect greater effects of age for more demanding language processes. Specifically, if increases in reading time at sentence and clause boundaries are indicative of the cognitive workload associated with semantic integration, then older adults would be more likely to show a reduced parafoveal preview benefit as a function of wrap-up. Although Rayner and colleagues (2010) have found some evidence that the preview benefit is relatively well preserved in older adults, they did find age-related reductions in the perceptual span in conditions where participants showed longer gaze times. Thus, when older adults were allocating more effort, perhaps to more difficult sections of the text, only then was the preview benefit reduced more for older readers. To the extent that wrap-up effects are resource consuming, older adults may be more taxed in processing at clause and sentence boundaries, and thus, would show less parafoveal preview on the post-boundary word. However, under a separate language interpretation view (Caplan & Waters, 1999), there should be no age deficits in wrap-up or in the effects of wrap-up on the parafoveal preview benefit.

Chapter II

Methodology

Participants

Participants were 27 younger adults (M_{age} = 21.57 SE = .56) and 22 older adults (M_{age} = 68.36 SE = 1.28) from the Champaign-Urbana area. Younger adults who volunteered for the study were undergraduate students between the ages of 18 and 30 from the University of Illinois at Urbana-Champaign. Older adult participants were volunteers from the local community. Participants received either course credit or $10 remuneration for their participation in the experiment. Individuals were native speakers of English and reported no history of any major health issues. Both younger and older participants self-reported their ratings of health, vision, and hearing as good or better. Participants were tested for visual acuity and had at least 20/30 corrected vision, or better.

Table A1 shows the means and standard errors for age, education, vocabulary, verbal working memory, working memory, and baseline reading speed for younger and older adults as well as the correlations between these variables for the total sample. There were no significant differences between the two groups in education, $t(44) = 1.31$, $p > .15$. The advanced vocabulary and extended range vocabulary tests from the Educational Testing Service Kit of Factor Referenced Cognitive Tests (Ekstrom, French & Harman, 1976) were used to measure vocabulary ability. The two measures of vocabulary were combined into one standardized composite ($\alpha = .89$). Older adults performed significantly better on tests of vocabulary, $t(44) = 4.38$, $p < .01$.

The loaded reading span task, as described in Stine and Hindman (1994), was used to measure verbal working memory capacity (vWM) and non-verbal working memory capacity

(WM) was assessed with the Letter Number Sequencing test of the Wechsler Adult Intelligence Scale (WAIS-III-R; Wechsler, 1997). While there were no differences between younger and older adults in WM, $t < 1$, younger adults did outperform older adults on the reading span task, $t(44) = 2.64$, $p < .01$. The baseline-reading rate was calculated for each participant as the average gaze duration across all words the participant read during the experiment. There were no significant differences between the younger and older adults in baseline-reading rate, $t < 1$.

Apparatus

Sentences were presented on a 19-in ViewSonic P225f monitor set to a resolution of 1,024 x 768. Two Dell 3.20 GHz computers controlled the eye-tracking system. An SR Research Eye-Link II (Ontario, Canada) head mounted eye tracking system monitored gaze location of the participant's right eye. The head mounted eye tracker samples at a rate of 500Hz and has good spatial and temporal resolution. The instructions and passages were displayed in a white, TrueType font (Courier New, size 16) on a black background. Participants were seated approximately 96.5 cm from the monitor, such that three letters subtended about 1 degree of visual angle. While most sentences were larger than 80 characters and, as such, did not fit on one line, both the target and post-target word always occurred before the end of the line.

Materials and Design

The materials for the current study consisted of 65 passages, which included 36 experimental items, 24 filler items, and five practice items. Two variables were factorially manipulated by crossing word position (sentence-final, clause-final, clause internal) and parafoveal preview (word preview, non-word preview) within the experimental items. An example sentence is presented in Table **A2**. In the sentence-final condition, the target word N appeared in the sentence-final position and the target word N+1 was the first word of the following sentence. In the clause-final condition, the target word N appeared at a comma-marked clause boundary and the target word N+1 was the first word of the next clause. In the sentence-internal condition, the target words N, N+1, and N+2, appeared in sentence-internal positions. All target and post-target words were the same for each item across all conditions. Word N was between 4 and 8 letters long (M = 5.69) and word N +1 was between 4 and 9 letters long (M = 6.13). Word frequency was estimated with the Hyperspace Analogue to Language frequency norms from the English Lexicon Project (Balota et al., 2007). The natural log of word frequency ranged between 7 and 12 (M = 9.56) for word N and between 7 and 15 for word N +1 (M = 10.89). Across lists, sentences within each condition were matched for word frequency and word length for both words N and N+1 such that there were no significant differences in length or frequency between conditions in any list. For each stimulus sentence, target words N and N+1 were always the same word across the three levels of Word Position.

For word N +1, the non-word previews were always a random string of visually dissimilar consonants of the same length of the preview word. These consonant strings were generated at random from the MCWord orthographic word-form database (Medler & Binder, 2005). If any of the first 4 characters of the non-word preview matched or were visually similar to the word preview for that condition, that character was changed. This was done in an effort to produce the largest preview benefit (see Henderson & Ferreria, 1990). The distance between word N and N+1 were kept constant across the word position condition by matching the distance of word N and N+1 and inserting a period (in the sentence-final condition) or comma (in the clause-final condition) within this space without increasing the distance. Thus, the clause and sentence conditions were not confounded with increased visual eccentricity of word N+1 (which would decrease the parafoveal preview), compared to the clause internal condition. Therefore, any differences in the clause or sentence position conditions on word N+1 preview cannot be attributed to extra spacing between conditions.

Six counterbalanced lists were constructed by rotating each condition across each list, following a Latin square design. Sentences were arranged in a fixed but random order for presentation. Simple yes/no questions were asked on one third of the trials to ensure the participant was reading for comprehension. Participants were allocated to each list following a Latin square design, which was constructed separately for both younger and older adults. This resulted in a final 2 x 2 x 3 mixed effects design with age as a between subjects variable and word position and preview as within subjects variables.

Procedure

The experimental session lasted between 60 and 90 minutes. After participants completed a brief demographic questionnaire, they were seated in front of the presentation computer for the eye-tracking portion of the experiment. Participants read instructions on the screen asking them to read each passage for comprehension and informing them that that they would have to answer questions about the sentences on a random number of trials. After reading the instructions, participants placed their heads in a chinrest to minimize head movements and were fitted with the head-mounted eye-tracker. After the tracker was aligned and calibrated, the participant began the practice and experimental trials. A fixation correction was presented between each trial in order to check that the system was still correctly calibrated. In cases where a minor drift occurred, the system auto-corrected before the beginning of the trial. In cases where calibration was lost, the system was completely recalibrated before moving forward. A gaze-contingent boundary change paradigm (Rayner, 1975) was used to manipulate the parafoveal word information on word N+1. Figure A1 shows an example sentence from this study using the boundary change paradigm. On non-word preview trials (no preview), when a reader's eye crossed an invisible boundary located in the space between the second to last and last letter of word N (see Henderson & Ferreria, 1990), the non-word was changed to the target word N+1.

After the eye-tracking portion, participants were then administered a brief battery of individual difference measures: the vocabulary, WMC, and vWM tasks. Lastly, participants completed a debriefing interview that probed their awareness of the gaze-contingent display change. They were asked if they noticed anything strange about the appearance of the text in the experiment. If they answered no, they were probed with a more specific question, asking them if they noticed anything flashing or changing. If they answered yes to either question, they were asked how many times they noticed any changes.

Analyses

Participants who explicitly noticed the boundary change and reported seeing three or more display changes were not included in the analyses (N = 3). Of the resulting data (N_{Young} = 24; N_{Old} = 22), fixations were cleaned and trimmed. Fixations under 80 ms that fell within a half degree of visual angle were incorporated into one fixation. Remaining fixations under 80 ms and over 1,000 ms were discarded from the data analyses. Trials in which word N or word N+1 were not initially fixated were discarded and all trials were removed in which a display change did not complete within the latency of the forward moving saccade to N+1 that triggered the boundary. These trials were selected using the procedure described in Risse and Kliegl (2011), in which the delay between the boundary trigger and display change were calculated for each change trial and compared against the time between the onset and offset of the right-bounded saccade that triggered the boundary change. Overall, this data trimming procedure resulted in 19.3% of the experimental trials being excluded from analyses for younger adults and 20.9% of the trials for older adults, which is on par with other studies using the boundary change paradigm (see Chase et al., 2005; Hyönä et al., 2004; White et al., 2005). Missing data were distributed evenly across conditions.

Analyses were conducted using linear mixed effects modeling (lme; Snijders & Bosker, 1999), with subjects and items specified as crossed random effects. SAS Proc Mixed (Version 9.1) was used to fit all models. By assessing variance associated with both subjects and items simultaneously, lme allows the researcher to perform all statistical analyses within a single model, avoiding the need for separate F1 (subject) and F2 (items) repeated measures ANOVAs.

As such, the use of these modeling techniques is becoming more prevalent in the psycholinguistic literature (Baayen, Davidson & Bates, 2006; Locker, Hoffman, & Boviard, 2007; Quene & van den Bergh, 2004, 2008; Jaeger, 2008). Moreover, lme models are capable of modeling predictors of subject and item level variability simultaneously and are capable of modeling both discrete and continuous variables within the same analysis. Additionally, lme models are robust against missing data and can model variance and covariance explicitly, allowing for violations of sphericity and homogeneity of error variance, which occur often in naturally obtained data sets (Snijders & Bosker, 1999). All model parameters were estimated using maximum likelihood estimation. For all categorical fixed effects (both omnibus tests and contrasts), I report the F statistic of the Type-III fixed effect, degrees of freedom (*df*; denominator *df* were estimated using the containment method, though other estimations did not result in differences in significance; see Schaalje, McBride, & Fellingham, 2001), and corresponding *p*-values.

Chapter III

Results

The data are presented in the following sections: (1) Effects on word N (2) Effects on word N+1 and (3) Individual differences in wrap-up and the preview benefit. Across all analyses, significant variability occurred across both subjects and items. Two first pass fixation measures, first fixation duration (FFD) and gaze duration (GD), are reported for word N and word N+1. FFD is the duration of the first fixation on a word and GD is the sum of all fixations on a word prior to moving to another word. Additionally, I report regression path duration (RPD; also called go-past time) for word N, which is the sum of all fixations from when a reader first enters the target word (including rereading earlier words), until he or she moves past the word to the right. This measure is considered a later measure of processing that is related to integration processes during reading (cf. Rayner, 1998), and thus is of interest for examining wrap-up effects.

Effects on Word N

Table A3 shows the mean reading times for word N. To test the independent and joint effects of age and wrap-up on reading time, three separate 2 (Age: young, old) x 3 (Word Position: sentence-internal, clause-final, sentence-final) linear mixed effect models were fit to FFD, GD, and RPD on target word N. When the pattern was similar for all three measures, I report these concurrently. Neither Age, $F_{\text{FFD}}(1, 1202) = 1.51$, $p >. 20$; $F_{\text{GD}}(1, 1202) = 1.10$, $p >. 20$; $F_{\text{RPD}}(1, 1202) = 1.93$, $p > .15$, nor the Word Position X Age interaction, $F_{\text{FFD}}(1, 1202) = 1.44$, $p >. 20$; $F_{\text{GD}}(1, 1202) = 1.92$, $p > .15$; $F_{\text{RPD}}(1, 1202) = .39$, $p > .20$, significantly predicted reading time on word N. However, the Word Position effect was significant, $F_{\text{FFD}}(1, 1202) = 7.37$, $p <$

.001; $F_{GD}(1, 1202) = 8.81, p < .001$; $F_{RPD}(1, 1202) = 9.02, p < .001$. Post-hoc contrasts revealed that when word N marked a clause boundary, it was fixated for significantly longer than when it occurred in a sentence-internal position, $F_{FFD}(1, 1202) = 7.32, p < .01$; $F_{GD}(1, 1202) = 8.10, p < .01$; $F_{RPD}(1, 1202) = 6.91, p < .01$. Similarly, when word N marked a sentence boundary, it was fixated for significantly longer than when that word occurred in a sentence-internal position, $F_{FFD}(1, 1202) = 13.88, p <. 001$; $F_{GD}(1, 1202) = 16.87, p < .001$; $F_{RPD}(1, 1202) = 17.74, p < .001$. As seen in Figure A2, which plots the effect of word-position on GD for word N, these results clearly illustrate the wrap-up effect; when a word occurs at a clause or sentence boundary, reading times are longer than when these words occur in a sentence-internal position (Just & Carpenter, 1980; Rayner et al., 1989, 2000; Stine-Morrow et al., 2010). There were no significant differences between the clause and sentence conditions in FFD, $F(1, 1202) = 1.12, p >. 20$, or GD, $F(1, 1202) = 1.70, p > .15$, but there did exist a marginal difference in RPD, $F(1, 1202) = 2.65, p = .10$, such that words in the sentence-final position had a longer RPD than words in the sentence-internal position.

Effects on Word N+1

Table A4 shows the mean reading times for word N+1. Separate omnibus 2 (Age: young, old) x 3 (Word Position: sentence-internal, clause-final, sentence-final) x 2 (Preview: word preview, non-word preview) linear mixed effect models were fit to first-pass measures of reading time (FFD; GD). When interactions with Word Position (a 3-level variable) were found, these were decomposed using contrasts to test for the effects of wrap-up (Clause wrap-up: sentence-internal vs. clause-final; Sentence wrap-up: sentence-internal vs. sentence-final). Additionally, contrasts between the preview and no-preview condition were calculated for each level of Word

Position, to test for the presence of a significant preview benefit at sentence-internal, clause-final, and sentence-final positions.

First fixation duration. Age was marginally related to FFD on word N+1, $F(1, 1225) = 3.13$, $p = .08$, such that older adults spent approximately 15 ms longer on word N+1 than their younger counterparts, regardless of condition. There was a significant effect of Preview on word N+1, revealing the preview benefit effect, $F(1, 1225) = 33.81$, $p < .001$. That is, words with an initial non-word preview were, on average, fixated for 34 ms longer than those with a valid preview. Additionally, while word position did not have a significant main effect, $F(1, 1225) = 1.63$, $p > .15$, the Word Position X Preview interaction was marginally significant, $F(1, 1225) = 2.51$, $p = .08$. As seen in Figure A3, this suggests that Word Position moderated the size of the preview benefit. Contrasts revealed that the Clause Wrap-up X Preview interaction was significant, $F(1, 791) = 2.04$, $p = .04$. However, the Sentence Wrap-up X Preview interaction did not reach significance, $F(1, 780) = 2.50$, $p = .105$. The size of the preview benefit (non-word preview – word preview) was 41 ms in the sentence-internal condition, $F(1, 1230) = 24.68$, $p < .001$. However, the preview benefit was 17 ms in the clause condition, $F(1, 1230) = 4.55$, $p = .03$ and 23 ms in the sentence-final condition, $F(1, 1230) = 8.16$, $p < .01$. These effects did not interact with age, as the 3-way interaction for FFD was non-significant ($F < 1$). Thus, in the earliest first-pass measure of processing, there was evidence that both sentence and clause wrap-up reduced the size of the preview benefit similarly for both younger and older readers.

Gaze duration. GD was longer for words without a valid parafoveal preview than those with a valid preview, $F(1, 1225) = 25.56$, $p < .001$. This effect was moderated by a significant Word Position X Preview interaction, $F(1, 1225) = 4.08$, $p < .05$, as shown in Figure A4. While the Clause Wrap-up X Preview interaction was not significant, $F < 1$, the Sentence Wrap-up X

Preview effect was, $F(1, 780) = 6.50$, $p < .01$. The size of the preview benefit was 53 ms in the sentence-internal condition, $F(1, 1230) = 18.97$, $p < .001$, and 42 ms in the clause-final condition, $F(1, 1230) = 12.96$, $p < .001$, but there was no evidence of a significant preview benefit in the sentence-final condition, with a difference between the preview and no preview conditions of only 8 ms, which was not significantly different from zero, $F > 1$; $p > .4$.

Importantly, there existed a significant Word Position X Preview X Age interaction, $F(1, 1225) = 3.02$, $p = .05$, suggesting that the effects of wrap-up on the preview benefit were moderated by age. Figure A5 illustrates this effect, plotting the preview benefit difference score at all three word positions, for both younger and older readers. This interaction was decomposed by fitting age separate models to test the Clause Wrap-up X Preview and the Sentence Wrap-up X Preview interactions separately for younger and older readers. For younger adults, neither the Clause Wrap-up X Preview nor the Sentence Wrap-up X Preview interaction were significant, F's < 1. The preview benefit was 42 ms in the sentence-internal condition, $F(1, 641) = 7.23$, $p < .01$, 37 ms in the clause-final condition, $F(1, 641) = 5.42$, $p < .05$, and 34 ms in the sentence-final condition, $F(1, 641) = 4.35$, $p < .05$. For older readers, while the Clause Wrap-up X Preview interaction was not significant, $F < 1$, the Sentence Wrap-up X Preview interaction was significant, $F(1, 342) = 13.28$, $p < .001$. The size of the preview benefit was 64 ms in the sentence-internal condition, $F(1, 549) = 13.04$, $p < .001$) and 47 ms in the clause-final condition, $F(1, 549) = 7.71$, $p < .01$. However, there was no evidence of a preview benefit in the sentence-final condition, with a comparison of the no preview and preview conditions yielding a difference of -19 ms, which was not significantly different from zero, $F(1, 549) = 1.58$; $p > .20$. The findings from the analysis on gaze durations suggests that the size of the preview benefit is constrained by sentence wrap-up only among older adults, who received no parafoveal preview benefit for words at the beginning of sentences, presumably due to the increased processing load associated with sentence wrap-up.

Although GD and FFD often yield similar results in eye-movement studies of reading (see Rayner, 1998), the results here yield somewhat diverging accounts between the two measures. It appears that in the earliest measure of processing (FFD), sentence and clause wrap-up affects the preview benefit similarly for both younger and older adults, with both groups showing evidence for a reduction in the size of the preview benefit in the clause-final and sentence-final conditions, compared to the sentence-internal condition. By the later first pass measure of gaze duration, however, the effects of wrap-up on the preview benefit had diminished among younger adults, while the effect of sentence wrap-up on the preview benefit persisted only among older adults, suggesting that sentence wrap-up was more effortful for the older readers.

Individual Differences in Wrap-up and the Preview Benefit

Association between wrap-up and the preview benefit. To make a stronger argument that it is the effect of wrap-up that is reducing the size of the preview benefit, I tested whether the average time allocated to clause wrap-up or sentence wrap-up on word N is associated with the size of the preview benefit on N+1. I computed estimates of sentence and clause wrap-up separately for each individual. For clause wrap-up, gaze-durations on word N were regressed onto the dummy-coded contrast for clause wrap-up (0 for sentence-internal and 1 for clause-final) for each individual. To estimate sentence wrap-up effects, gaze-duration on word N was regressed onto the dummy-coded contrast for sentence wrap-up (0 for sentence-internal and 1 for sentence-final), separately for each individual. The resulting un-standardized regression coefficients represent each individual's relative increase in gaze duration (in milliseconds) at clause boundaries and sentence boundaries (see Lorch & Myers, 1990).

Similarly, I calculated two estimates of the parafoveal preview benefit separately for each individual. One estimate was calculated for the preview benefit in the clause-final condition by taking the gaze durations on N+1 in the clause-final condition and regressing these fixation times onto the dummy-coded preview condition variable (0 for preview, 1 for no-preview) separately for each individual. A separate estimate was calculated to estimate the average preview benefit in the sentence-final condition. This was accomplished by taking the gaze durations on N+1 in the sentence-final condition and regressing these fixation times onto the dummy-coded preview condition variable (0 for preview, 1 for no-preview) for each individual.

If the processes associated with wrap-up reduce the magnitude of the preview benefit, then a negative correlation should be found between the estimates of wrap-up and their corresponding preview benefits. As can be seen in Figure A6, which plots the preview benefit for each individual as a function of the magnitude of clause wrap-up (left-panel) and sentence wrap-up (right panel), this trend is found. Clause wrap-up was negatively correlated with the preview benefit in the clause boundary condition, but this effect was marginal, $r = -.28$, $p = .057$. Similarly, sentence wrap-up was negatively correlated with the preview benefit in the sentence boundary condition, $r = -.29$, $p = .051$. These results suggest that when readers show longer wrap-up effects on word N, they also show smaller preview benefits on the following word. However, because of the small sample size and the weak effects, these findings should be interpreted with some caution for now.

Individual differences: An exploratory analysis. Further analyses were aimed at examining if individual differences in vWM, vocabulary, and reading speed impact sentence and clause wrap-up or the preview benefit. These effects were explored using lme models, with vWM, vocabulary, and reading speed treated as continuous predictors. Though these individual difference measures did not appear to significantly impact any of the key outcomes, they are reported below for completeness. The effect of sentence and clause wrap-up on word N was not significantly moderated by reading speed, vWM, or vocabulary, all *F's* < 1, for FFD, GD, or RPD. Interestingly, there was also no evidence that reading speed, vWM, or vocabulary moderated the preview benefit on word N+1, all *F's* < 1. Lastly, considering that age moderated the effect of word position on the preview benefit of word N+1 in gaze duration (see Figure A5), a final goal was to test if this age difference could be explained by differences in vWM, reading speed, or vocabulary. However, after accounting for these variables by treating them as covariates in the model, the Word Position X Preview X Age interaction was not reduced, $F(1, 1219) = 3.02$, $p = .05$, which suggests that the age related differences cannot be explained by these individual difference measures.

Chapter IV

Discussion

Semantic Integration During Reading

Text comprehension involves the execution of immediate and incremental processes related to accessing lexical information, establishing sentence structure, and interpreting the semantic information in the text. That language processing is highly incremental does not preclude the existence of elaborative integrative processes that can occur periodically during reading. Wrap-up effects appear to be one such mechanism, in which the semantic representation is consolidated and integrated with new information at clause and sentence boundaries (Kintsch & van Dijk, 1978; Just & Carpenter, 1980; Haberlandt & Graesser, 1989; Rayner et al., 2000). Likely, there are dual processes ongoing in order to construct the mental representations underlying text comprehension, including linear and incremental processes (Pickering & van Gompel, 2006) and processes whereby segments of text (clauses and sentences) that are in attentional focus and active in working memory are integrated with prior information (i.e., input cycles; Kintsch & van Dijk, 1978).

In the current study, a key assumption of this semantic integration hypothesis of wrap-up was tested, namely that wrap-up effects should be resource demanding and, as such, reduce the size of the preview benefit across clause and sentence boundaries. The findings of the current study are consistent with this hypothesis. In measures of first fixation duration, which index very early first pass reading, the size of the preview benefit was reduced if it was preceded by a marked clause boundary or sentence boundary, compared to a condition in which the target word N+1 was not preceded by a clause or sentence boundary. While this effect was similar for younger and older adults in the earliest measure of processing, there was evidence of age differences in this effect by gaze duration. That is, in gaze duration, which reflects a slightly later measure of processing time (Inhoff, 1984; Rayner & Pollatsek, 1987; Rayner, 1998), the effect of wrap-up on the preview benefit had diminished among younger readers, indicating that wrap-up impacted parafoveal processing only very early on for this group. However, older adults continued to show disruption of the preview benefit into gaze duration, demonstrating no evidence for a preview benefit in the sentence-final condition. Under a semantic integration view of wrap-up effects, this suggests that sentence wrap-up was more costly for older adults, resulting in greater cognitive workload, which reduced the amount of parafoveal processing that could be accomplished on the post boundary word.

This semantic integration view is consistent with several theories of sentence and discourse processing. For example, in the Sausage Machine Parsing Model (Frazier & Fodor, 1978), early parsing analyses can be established in “phrasal packages” that operate within working memory constraints. Similarly, Kintsch and colleagues’ (Kintsch, 1988, 1998; Kintsch & van Dijk, 1978) Construction-Integration model, a computational model of discourse comprehension, includes a mechanism in which propositional content is offloaded across working memory cycles (i.e., input cycles or processing cycles) into long-term memory. In this model, propositions are constructed within a phrase or clause automatically through a spreading activation. Integration of these propositions into an input cycle occurs depending on surface characteristics of the text that define clause and phrase boundaries. At these boundaries, propositions are “chunked” together and this input cycle is integrated with information from prior input cycles that are still available in working memory.

The Cognitive Workload of Wrap-up

Recent studies (Hirotani et al., 2006; Hill & Murray, 2000; Warren et al., 2009) have proposed possible alternative explanations for wrap-up effects, explaining these peaks in reading time at clause and sentence boundaries in terms of lower-level oculomotor or prosodic monitoring mechanisms not related to the effortful processing demands of semantic integration at boundary sites. However, the findings from the current study suggest that the work to be done at the end of clause and sentence boundaries, presumably related to semantic integration, increase the cognitive processing load, which constrains parafoveal processing that occurs during normal reading. Additionally, the current study found that the size of both clause and sentence wrap-up was negatively related to the magnitude of the preview benefit.

It is crucial to note, however, that the findings from the current study do not necessarily conflict with the presence of a potential oculomotor or intonational mechanism, as suggested by Hill and Murray (2000) and Hirotani et al. (2006). However, the collective results of the current study would be difficult to explain under a strict dwell-time or oculomotor hypothesis in which wrap-up effects are fully explained by these low-level mechanisms (see pp. 438-439; Hirotani et al., 2006). As previously discussed, intonational boundaries (marked by punctuation), likely play a role in wrap-up, but this does not exclude a mechanism whereby semantic and discourse updating work occurs at sentence and clause boundaries. For example, the findings from Stine-Morrow et al. (2010) suggest that increasing boundary salience (by manipulating punctuation alone) can increase the magnitude of the clause wrap-up effect but importantly, this increase in processing time at minor clause boundaries, even if triggered by punctuation, results in reduced processing costs downstream, consistent with the semantic integration hypothesis of wrap-up effects.

Future research should further consider this potential intonational monitoring mechanism. Correct prosodic phrasing contributes positively to memory and comprehension of spoken language, especially for older adults (Kjelgaard, Titone, & Wingfield, 1999; Titone, Koh, Kjelgaard, Bruce, Speer, & Wingfield, 2006), and there is little doubt that these processes are utilized in reading as well (Fodor, 2002), though they are self-imposed by the reader. One argument could be made that the extra semantic work done at boundary sites occurs only because prosodic boundaries impose a pause and that this extra time is utilized by the system for added processing. However, one could consider an equally plausible hypothesis in which human prosody and grammar evolved because of cognitive capacity limitations in the language system (see Kintsch & van Dyke, 1978 p. 368; Longacre & Levinsohn, 1977 for a discussion). Thus, prosody and intonational boundaries may occur due to the need to package information in smaller chunks in order to maintain effective comprehension and production in the face of comparably small working memory capacities.

Differences between clause and sentence wrap-up. Often, the literature on wrap-up considers the processes occurring at clause boundaries and sentence boundaries to be highly similar. However, Just and Carpenter (1980) argued that there might be very different cognitive processes underlying clause and sentence wrap-up (and that there potentially exist other unique wrap-up processes at the end of even more major constituents, such as at the end of arguments in a discourse; Britton, 1994; see Stine-Morrow et al., 2008). Just and Carpenter (1980) argued that peaks in processing time at clause boundaries reflect points of integration across clauses, whereas sentence wrap-up is a special computational episode that includes other processes apart from linking information across clauses and sentences, such as searching for referents and handling inconsistencies and ambiguities within the sentence. Additionally Kuperman et al.

(2010) demonstrated that there is a reliable "end of line wrap-up" effect, in which extra processing also occurred at a line break during reading, independent of the presence of syntactic boundaries, which again suggests that low level or perceptual cues (i.e., reaching the end of a line) can trigger integrative processing.

While overall the data from the current study showed that readers responded to clause and sentence boundaries more similarly than not, there did appear to be some potentially important differences. While the magnitude of clause and sentence wrap-up effects were similar in first pass measures, there was some indication of differences in RPD, which includes re-reading time to earlier portions of the sentence. Readers did appear to show a difference in overall processing time in the sentence condition compared to the clause condition before the reader moved forward in the text.

Foveal load and the preview benefit. While a number of studies have examined the influence of foveal load on parafoveal processing (Henderson & Ferreria, 1990; White, Rayner, & Liversedge, 2005), only a very small number of unique effects have been investigated (e.g., effects of word frequency and garden path effects). The findings in the current study contribute to this line of research by demonstrating that the cognitive workload induced by sentence and clause wrap-up reduced the magnitude of the parafoveal preview of the post-boundary word. Considering that wrap-up effects are often conceptualized as "higher-order" processes (see Rayner, 2006), further research should examine the influence of other discourse processes on the parafoveal preview benefit, such as effects of referential cohesion or discourse level ambiguity.

Aging, Wrap-up, and the Parafoveal Preview Benefit

Overall, older adults were very similar to their younger counterparts in terms of their patterns of eye-movements during reading. However, there are some notable exceptions to this, discussed below.

Aging and wrap-up. No age differences were found in the effect of word position on processing time. Both younger and older adults showed increased fixation times on word N in the sentence-final and clause-final conditions, compared to the sentence-internal condition. Thus, there was no evidence of age differences in wrap-up on the target word N. This is in contrast to some studies using both eye-tracking (Stine-Morrow et al., 2010) and self-paced reading (Miller & Stine-Morrow, 1998; Stine, 1990), finding age differences in patterns of wrap-up. However, other studies have shown adult age equivalence in wrap-up (Stine et al., 1995), though typically at the cost of subsequent memory for text and comprehension among older adults. Considering that the individuals in the current study showed no variation in response to the simple comprehension probes, I could not investigate differences between good and poor comprehenders. Thus, future research will benefit from collecting more fine grained measures of offline comprehension in order to determine if the increased cognitive workload at clause and sentence boundaries results in better overall comprehension and memory.

Aging and the preview benefit. Rayner, Castelhano, and Yang (2009, 2010) and Risse and Kliegl (2011) have shown that, although there are some small age differences in the perceptual span during normal reading, older adults do show a preserved preview benefit during normal reading. The results of the current study are in line with these studies, suggesting that the covert attentional mechanisms that underlie eye movement control during normal reading remain intact with age, despite changes in visual acuity. However, Rayner et al. (2010) did note that the preview benefit was somewhat reduced among older adults when they spent more time fixating certain target words, likely due to processing difficulty in these cases. In a following section, I discuss the finding that the preview benefit was eliminated in the sentence-final condition among older adults only, which is consistent with Rayner's claim that extra processing load on the currently fixated word reduced the preview benefit exclusively for older readers.

Rayner and colleagues (Rayner, Reichle, Stroud, & Williams, 2006) argued that older adults might adopt a more "risky reading" strategy in order to compensate for general slowing, so that they maintain a baseline rate of reading that is similar to their younger counterparts. Part of this risky reading strategy involves a greater reliance on partial parafoveal information; older adults may process words in the parafovea more effectively, resulting in their skipping more words because they have already been identified. Though there was no direct evidence for a greater reliance on parafoveal information among older adults, there was a trend in the data whereby the older adults showed a larger preview benefit during normal reading (see Figure A5), which would suggest that they are relying more on parafoveal word information. However, this effect did not reach statistical significance.

Individual differences and the preview benefit. I tested for the presence of individual differences in verbal ability, vWM, and reading speed on the magnitude of the preview benefit. Although I found no significant differences, these null effects are somewhat interesting considering the prior research that has investigated these effects on the preview benefit. Chase, Rayner, and Well (2006) showed that individual differences in reading skill predicted the size of the preview benefit. However, the current study found no evidence supporting the view that individuals with higher verbal ability showed differences in the size of the preview benefit, which is interesting considering that literate older adults often show increased automaticity of lower level word identification (Lien et al., 2006), which would presumably free up resources during reading, resulting in earlier covert processing of the following word (i.e. a larger preview benefit; see Rayner et al., 2003).

The finding that vWM did not predict the preview benefit is in line with the findings of Kennison and Clifton (1995), who also found no effect of vWM on the preview benefit. In the current study, a more powerful test of this effect was conducted, considering that these analyses treated vWM as a continuous variable and included a larger range of variability in working memory capacity, including younger and older adults who varied significantly in their vWM scores. Though this finding is somewhat counterintuitive, considering the other research indicating cognitive capacity constraints on the parafoveal preview benefit, it does appear that there is little evidence that verbal working memory span is related to the size of the perceptual span. Lastly, Rayner, Slattery, and Belanger (2010) found that individual differences in reading speed impacted the perceptual span such that those who read faster had a larger perceptual span and preview benefit. However, no evidence of this was found in the current study; baseline reading speed did not contribute to the preview benefit and, likewise, there was no evidence that reading speed moderated the effect of wrap-up on the preview benefit.

Age related costs of wrap-up on the preview benefit. The most interesting finding in the current study was the significant 3-way interaction that was detected in gaze duration, indicating that there were age differences in the effects of wrap-up on the preview benefit. Specifically, while both groups responded similarly to the effects of wrap-up on the preview benefit in the earliest measures of processing, it appeared that older readers' parafoveal preview benefit was more disrupted by sentence wrap-up, showing effects in both first fixation duration and gaze duration. While sentence and clause wrap-up affected parafoveal processing for both younger and older adults very early on, the effects of sentence wrap-up persisted into later measures of processing only for older adults. In gaze duration, older readers showed a very robust preview benefit in the normal reading condition and a somewhat smaller but still significant preview benefit in the clause boundary condition. However, there was no evidence of a preview benefit in the sentence condition for older adults, with the mean preview benefit in this condition actually showing a reversal in trend, though this was not different from zero. The finding that first fixation duration and gaze duration revealed different results, while not typical, has been found in other reading studies. Some argue that first fixation duration and gaze duration tap different cognitive processes or different stages of a process (Inhoff, 1984; Rayner & Pollatsek, 1987), with first fixation duration indexing early and automatic operations while gaze duration can be affected by slower cognitive operations (see also Rayner, 1998). That wrap-up affects the preview benefit in first fixation duration is not surprising since the effects of interest are occurring before that word is even fixated (i.e., changes in the amount of parafoveal processing). However, for younger adults, this effect is not found in gaze duration, suggesting that wrap-up is not completely disruptive to the preview benefit for this group. However, the extra foveal load (Henderson & Ferreria, 1990) caused by sentence wrap-up significantly decreased the parafoveal preview of word N+1 for the older readers, affecting their gaze durations. These results are difficult to account for with a strictly resource-free mechanism whereby pauses during reading are triggered by punctuation or intonation.

Conclusion

Overall, this study examined age differences in the cognitive workload involved in wrap-up by examining the preview benefit under three conditions: during normal reading, at clause boundaries, and at sentence boundaries. While there was evidence for very early and immediate effects of wrap-up on parafoveal processing for both groups, it was only the older adults who showed an effect of sentence wrap-up on the preview benefit that persisted into gaze duration.

Future research will benefit from examining the cost of text difficulty (Haberlandt & Graesser, 1987; Osterhout, 1997; Warren et al., 2009) on the preview benefit at sentence and clause boundaries, in order to examine whether the cognitive workload at wrap-up is greater for more complex sentences. Additionally, the cognitive workload of wrap-up should be investigated among individuals with different levels of comprehension, in order to determine if increased cognitive workload at wrap-up results in better sentence memory and comprehension, as predicted by the semantic integration hypothesis of wrap-up (Just & Carpenter, 1980). While age differences were found in the effects of wrap-up on the preview benefit, these differences could not be accounted for by speed, working memory, or verbal ability differences. Thus, future research will benefit from further investigating the underlying mechanism responsible for the age difference found in the current study.

According to a separate resource interpretation view of language processing (Caplan & Waters, 1999; Waters & Caplan, 1996, 2001), there exists a separate, domain-specific system that supports online language processing and importantly, that this language specific resource is not sensitive to the same conditions that deplete controlled conscious verbal working memory resources, such as aging. The finding that sentence-final processing produced a reduction in the preview benefit only among older readers is at odds with the Caplan and Waters separate resource model, which predicts no age differences in online measures of language processing. Collectively, the findings from the current study suggest that wrap-up is a resource demanding process and that semantic integration at sentence boundaries may be less efficient with age, thus, resulting in a greater cognitive processing load.

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Appendix A

Tables and Figures

Table A1

Demographic and Individual Difference Measures: Means and SE's by Age and Correlations (total sample).

	Younger Adults		Older Adults		Correlations (Total Sample)				
Measures	Mean	SE	Mean	SE	1	2	3	4	5
1. Age	20.87	.57	68.36	1.28					
2. Education	15	.31	16	.31	.22				
3. Vocabulary	-.50	.10	.55	.22	.57	.54			
4. vWM	4.39	.39	3.49	.17	-.38	-.05	-.13		
5. WM	11.22	.45	10.54	.51	-.12	.16	.28	-.11	
6. ReadSpeed	237	6	245	8.	.11	-.11	-.21	-.11	-.30

Note. vWM = Verbal Working Memory; WM = Working Memory; ReadSpeed = baseline reading speed (in milliseconds). SE = Standard Error. Correlations with absolute value > .27 are significant at p = .05

Table A2

Example Sentences

Preview Condition	Word Position	Sentence
Preview	SI	After the children watered the baby oak *tree* <u>next</u> to the house, they could go play.
	CF	After the children watered the baby oak *tree,* <u>next</u> on their list was watering the garden.
	SF	The children had watered the baby oak *tree*. <u>Next</u> on their list was watering the garden.
No Preview	SI	After the children watered the baby oak *tree* <u>(fcrg) next</u> to the house, they could go play.
	CF	After the children watered the baby oak *tree,* <u>(fcrg) next</u> on their list was watering the garden.
	SF	The children had watered the baby oak *tree*. <u>(Fcrg) Next</u> on their list was watering the garden.

Note. SI = Sentence-internal; CF = Clause-final; SF = Sentence-final; Word N is in *italics*; Word N+1 is <u>underlined</u>.

Table A3

Mean First Fixation Duration, Gaze Duration, and Regression Path Duration on Word N as a Function of Word Position and Age (in milliseconds).

Word Position	Age Group	FFD	GD	RPD
	Young			
SI		210 (8)	239 (13)	295 (36)
CF		232 (8)	276 (13)	383 (36)
SF		236 (8)	287 (13)	416 (36)
	Old			
SI		232 (8)	273 (14)	377 (39)
CF		237 (8)	283 (13)	421 (38)
SF		244 (8)	293 (14)	470 (38)
	Total			
SI		221 (6)	256 (10)	336 (28)
CF		235 (6)	279 (10)	402 (27)
SF		240 (7)	290 (10)	442 (27)

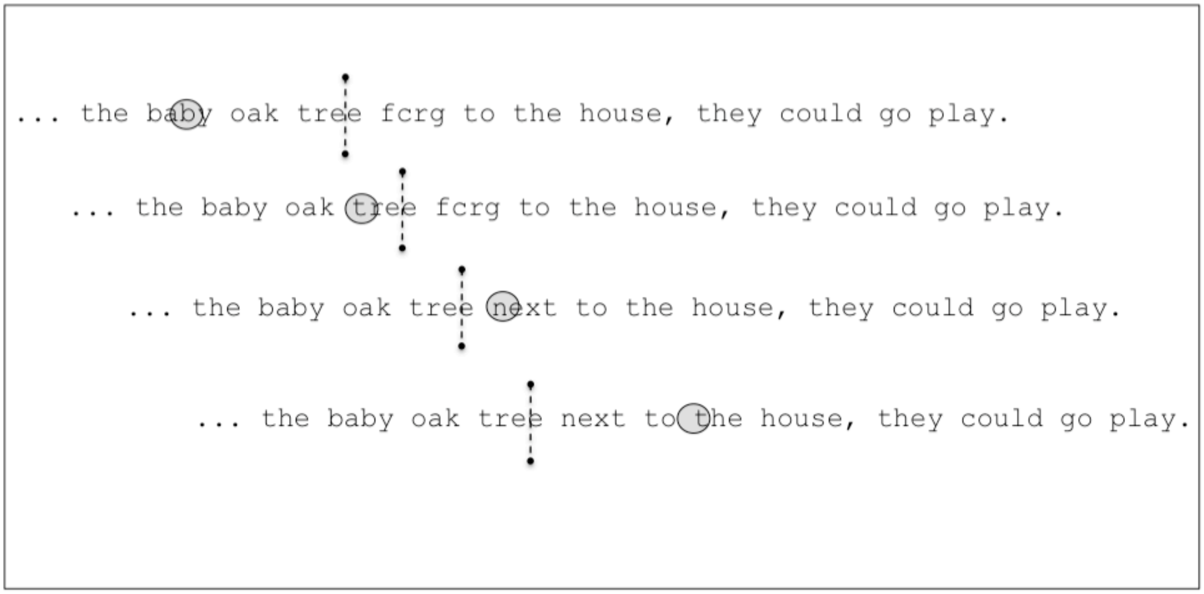
Note. RT = Reading Time. FFD = First Fixation Duration; GD = Gaze Duration; RPD = Regression Path Duration; WP = Word Position; SI = Sentence-internal; CF = Clause-final; SF = Sentence-final. Between-subject standard errors are in parentheses.

Table A4

Mean First Fixation Duration and Gaze Duration on Word N+1 as a Function of Word Position, Preview, and Age (in milliseconds).

		Younger Adults		Older Adults		Total	
RT	WP	Word N+1 Preview		Word N+1 Preview		Word N+1 Preview	
		No Preview	Preview	No Preview	Preview	No Preview	Preview
FFD	SI	252 (9)	222 (9)	269 (10)	219 (10)	261 (7)	220 (7)
	CF	230 (9)	210 (9)	248 (10)	235 (10)	239 (7)	223 (7)
	SF	237 (9)	220 (9)	263 (10)	235 (10)	250 (7)	228 (7)
GD	SI	307 (16)	266 (16)	321 (17)	258 (17)	315 (12)	262 (12)
	CF	284 (16)	247 (16)	324 (17)	276 (17)	304 (12)	262 (12)
	SF	281 (17)	247 (16)	273 (17)	293 (17)	277 (12)	270 (12)

Note. RT = Reading Time. FFD = First Fixation Duration; GD = Gaze Duration; RPD = Regression Path Duration; WP = Word Position; SI = Sentence-internal; CF = Clause-final; SF = Sentence-final. Between-subject standard errors are in parentheses.



Note. The circle represents the position of the eye in the sentence. The invisible boundary trigger is marked in this example. After the eye crosses the boundary, the non-word fcrg is replaced with the target word next, without the reader's awareness of the change.

Figure A1. Example of Sentence Using the Boundary Change Paradigm.

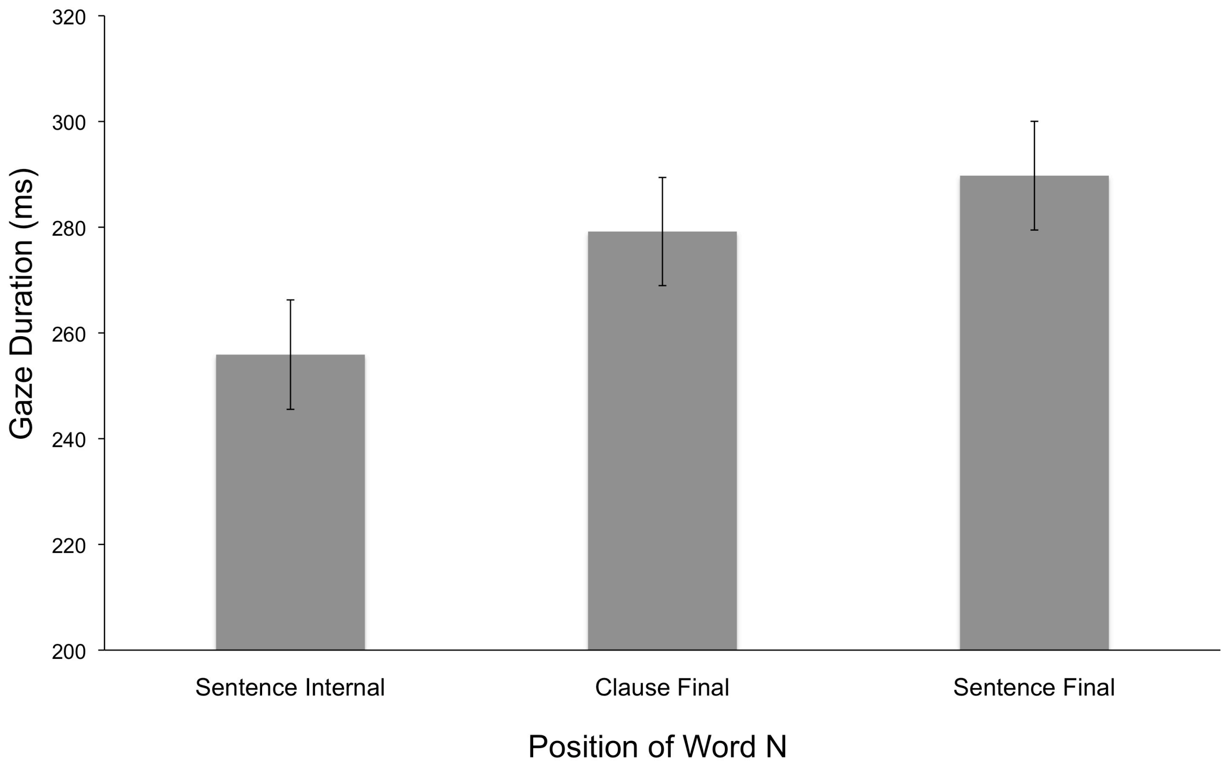


Figure A2. Gaze Duration (in Milliseconds) on Word N as a Function of the Position of Word N.

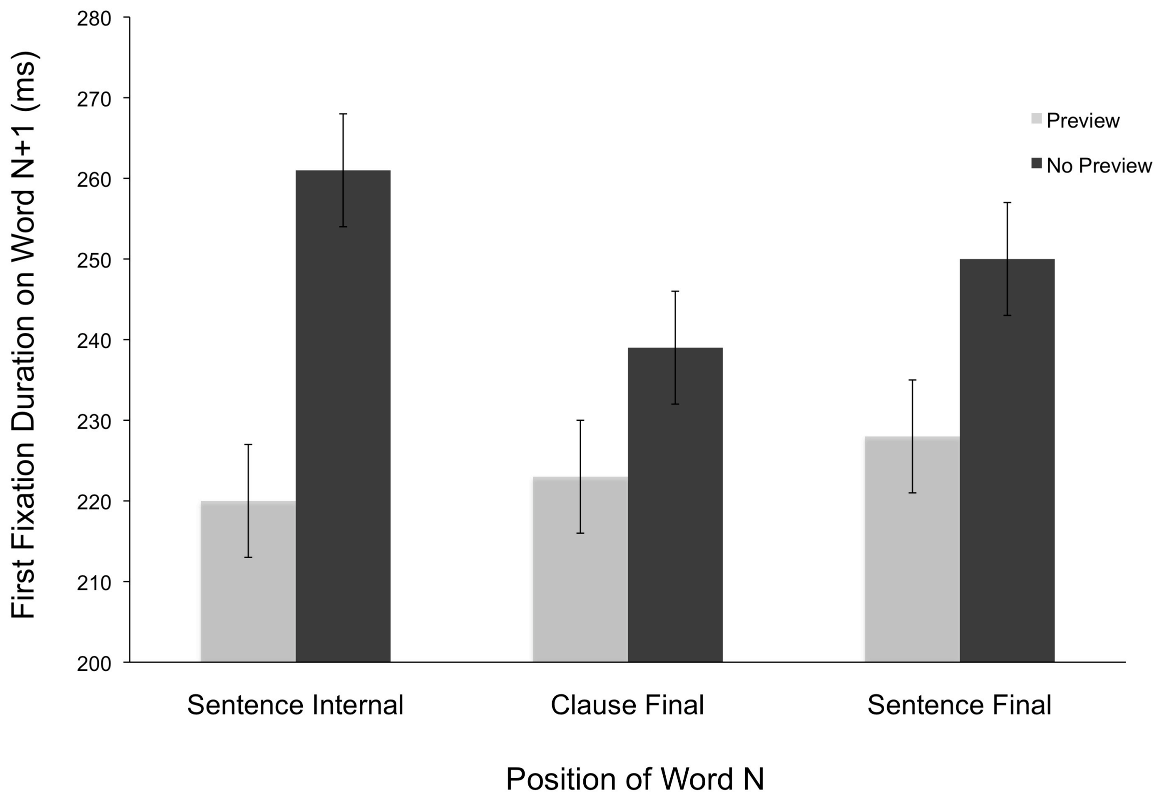


Figure A3. First Fixation Duration (in Milliseconds) on Word N+1 as a Function of Position of Word N and Preview Condition.

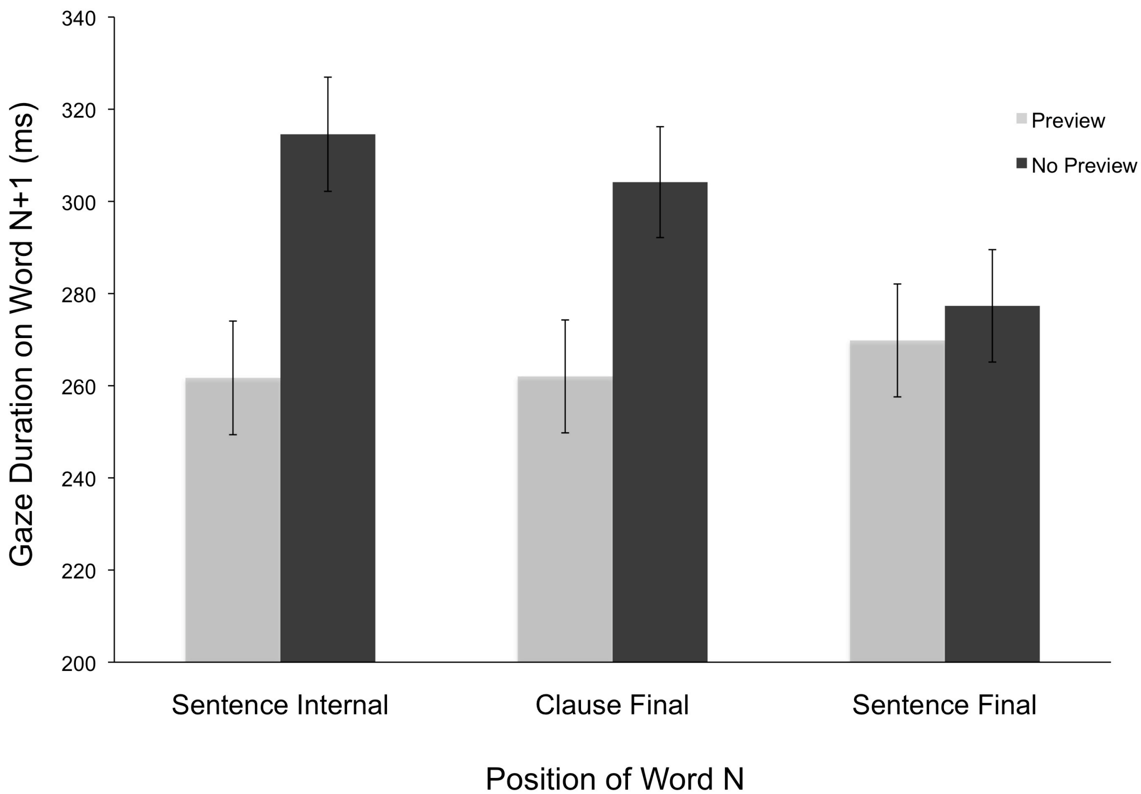
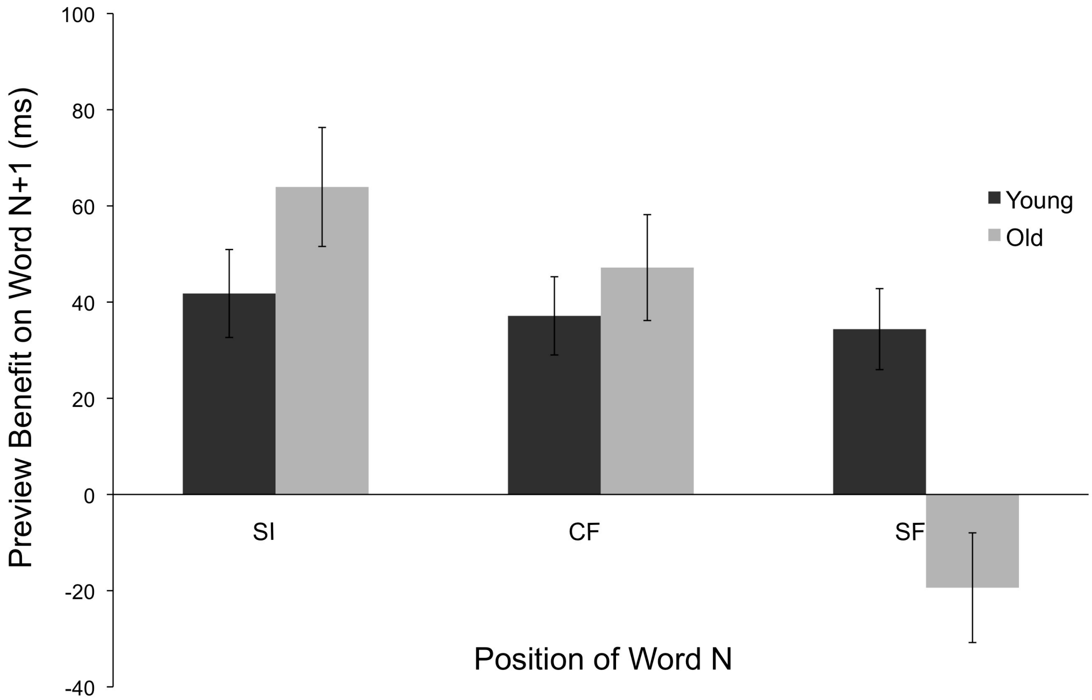
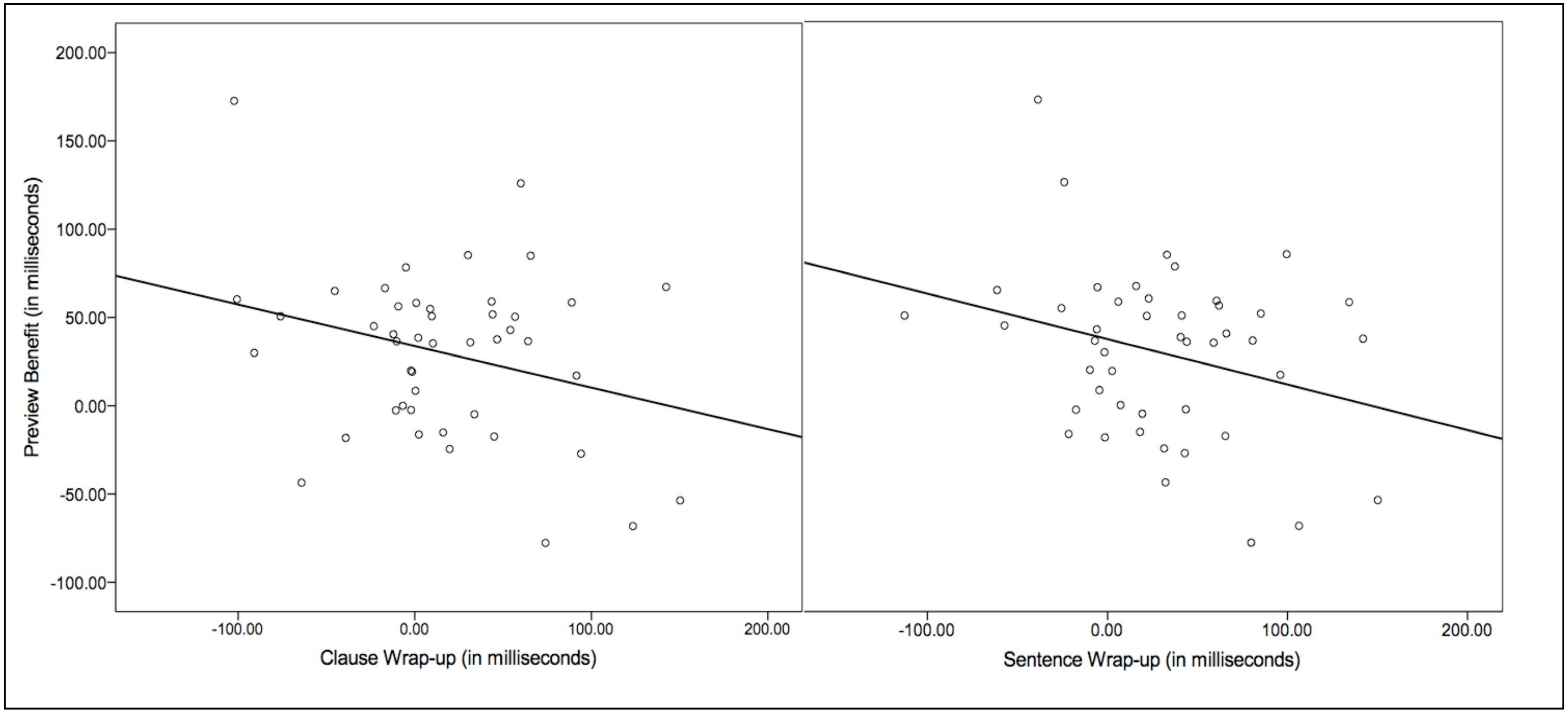


Figure A4. Gaze Duration (in Milliseconds) on Word N+1 as a Function of Position of Word N and Preview Condition.



Note. SI = Sentence-Internal; CF = Clause-Final; SF = Sentence-Final; Preview benefit calculated as difference in gaze duration between the preview and no preview conditions.

Figure A5. Preview Benefit as a Function of Age and Position of Word N.



Note. The left panel is the association between clause wrap-up on word N (difference between sentence-internal and clause-final conditions) and the preview benefit in the clause-final condition for word N+1. The right panel is the association between sentence wrap-up (difference between sentence-internal and sentence-final conditions) on word N and the preview benefit in the sentence-final condition for word N+1. See Results section for description of calculations for each panel.

Figure A6. Association Between Subject Average Wrap-Up on Word N and the Preview Benefit on Word N+1.